ORIGINAL ARTICLES

STUDIES ON *SCHISTOCERCA GREGARIA* FORSK.

VIII.* INFLUENCE OF CARBON DIOXIDE ON DEVELOPMENT OF BLACK PIGMENTATION IN *SCHISTOCERCA GREGARIA* FORSK

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(With Plates LVII-LIX)

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I. INTRODUCTION

It is well known that *Schistocerca gregaria* Forsk. hoppers show marked colour variations, ranging from light green to dense black with yellow spots. It is held by Uvarov [1928], and others, that this coloration is connected with the 'phases'—*solitaria* and *gregaria*. A typical 'non-swarming' or a *solitaria* hopper is almost spotlessly light green, while a typical 'swarming' or a *gregaria* hopper has extensive black pattern. Intermediate colour grades are not uncommon. In fact the grading, from spotlessly green to intense black, is so gradual that it is impossible, on the basis of coloration, to draw a line between the so-called swarming and non-swarming forms. For this reason some investigators recognise the following forms : *solitaria*, *transiense*, and *gregaria* ; and yet others *solitaria*, *dissocians*, *congregans* and *gregaria*. Nor is the coloration of a hopper predetermined or fixed. A non-swarming green hopper, even in the course of a single moult, may acquire the colour compliment of a 'regulation' swarming-type hopper and *vice versa*. Thus the coloration of a hopper, for example in the fifth instar, is practically independent of its coloration at birth. It is well known that the locust hoppers when bred crowded together retain, if born as such, or develop the colour patterns characteristic of the hoppers of a swarm. On the other hand, when bred singly, if born green they do not develop the black pattern, and if born black they lose their colour after a moult or two and finally acquire the green coloration characteristic of a non-swarming phase hopper.

It has been possible, in more ways than one, to induce, in the originally pure green hoppers, the coloration of the swarming-type without resorting to 'crowding'. The production of black pattern in the hoppers bred isolated, but forced to undergo muscular exertion has already been described [Husain and Mathur, 1936]. In this paper it is shown that the black pigmentation of the same pattern as is found in gregarious hoppers in nature, or in hoppers bred crowded, can be developed in hoppers bred isolated, if the concentration of carbon dioxide in the atmosphere of the rearing cage is kept high enough.

II. MATERIAL AND METHOD

Freshly hatched hoppers were reared in cages of fine wire-gauze. Each cage was a cylinder measuring six inches in length and 1·25 inches in diameter. These cages were placed in a glass cylinder (14 inches in height and 8 inches in diameter),

and were arranged along its wall at a distance of about one inch from each other. In the middle and near the bottom of the glass-cylinder, opened the delivery tube of a carbon dioxide generator. A constant current of carbon dioxide was allowed to pass into this cylinder. The mouth of this cylinder was covered over with a card board; thus any excess of air could pass out freely. The concentration of carbon dioxide in the cylinder, three inches above the bottom, was maintained, approximately, at three per cent, by volume. In some of the experiments carbon dioxide was generated by the action of hydrochloric acid on marble. In order to remove all trace of hydrochloric acid fumes from the gas, it was bubbled through water before being introduced into the rearing cylinders. In other experiments commercial carbon dioxide gas under pressure (in cylinders) was used.

Four of the experiments were carried out in the rearing room at an average temperature of 30°C.; and experiments V and VI were conducted in electric thermostats at constant temperatures of 40°C. and 44°C. Each experiment had a control and the hoppers belonging to the same hatching and isolated in similar cages, were reared in similar glass cylinders. Thus the control hoppers and the experimental hoppers were under identical conditions, except for the excess of carbon dioxide in the case of the hoppers under experiments. The food supply, which was renewed thrice a day, consisted of cotton or cabbage leaves, as specified in individual experiments, and this kept the relative humidity high, (80—90 per cent).

III. Observations

Before entering upon the details of the observations made, a word of explanation with regard to the influence of temperature on the intensity and extent of black pigmentation, acquired by the hoppers bred crowded, is necessary. Other factors being constant, the intensity and extent of black pigmentation within certain limits, varies inversely with temperature. At 30°C., for example, the black pigmentation of hoppers bred crowded is very pronounced, at 40°C. it becomes much reduced, while at 44°C., the hoppers are almost whitish.

It may be mentioned here that an isolated hopper reared, in an atmosphere containing three per cent carbon dioxide, at a particular temperature closely resembles, so far as the intensity and extent of black pigmentation is concerned, the hoppers bred crowded at that particular temperature. Thus a hopper reared isolated at 30°C. in an atmosphere containing higher concentration of carbon dioxide, will acquire approximately the same intensity and extent of black pigmentation in the fifth instar as a crowded hopper of that instar at that temperature. Husain and Ahmad [1936] have studied the development of black pigment in crowded hoppers of *Schistocerca gregaria* at certain constant temperatures and have fully described and illustrated (with coloured plates) the coloration of the hoppers at each stage. For this reason it has not been considered necessary to describe the coloration at each stage and the descriptions of typical V stage hoppers only, as obtained under the influence of carbon dioxide, are given.

In what follows the term "*Black type*", refers to that intensity and extent of black pigmentation, which a hopper bred crowded normally acquires at a particular temperature. It must be remembered that a hopper referred to as "*Black type*", say at 40°C., shows the black pigmentation typical of the hoppers reared crowded at 40°C., but may not be as strongly pigmented as a hopper bred crowded at 30°C. In certain cases the intensity of pigmentation, obtained under the influence of carbon dioxide, was even higher than that of the hoppers bred crowded at that temperature. Such cases have been referred to as "*strongly black type*". *Green type* refers to hoppers devoid of all black markings, but the term does not indicate the intensity of the basic green colour. For coloured plates illustrating the two types reference may be made to in an earlier publication [Husain and Mathur, 1936].

A. Experiment I

The hoppers in this experiment were taken from two hatchings.

History.—Reference No. P 54 and P 57.

The solitary phase adults of both the pairs were collected from Pasni (Makrān coast) on 8th August 1932, and were received at Lyallpur on 19th August 1932, and reared in pairs in wire-gauze cages measuring 9-in. × 9-in. × 9-in. Females P 54 and P 57 laid a cluster of eggs each on 31st August 1932. Both the egg pods hatched on 14th September 1932, and the hatchings were pure green, the progeny of P 54 and P 57 consisting of 62 and 64 green hoppers respectively. Thus the hoppers from both these hatchings showed distinct '*solitaria*' tendency.

Conditions.—The hoppers were isolated and bred in an atmosphere containing excess of carbon dioxide, from 14th September 1932 onwards.

Food.—Cotton leaves were provided for feeding and were changed thrice a day.

The temperature of the laboratory where the hoppers were reared was :—

Highest maximum . .	35°C.	Highest minimum . .	32°C.
Lowest maximum . .	29·5°C.	Lowest minimum . .	25°C.
Average maximum .	31·8°C.	Average minimum . .	27·7°C.

Average mean temperature :—29·7°C.

B. Experiment II

History.—Reference No. P 55.

The solitary phase adults were collected from Pasni on 8th August 1932 and were received in the laboratory on 19th August 1932. They were placed in pairs in wire-gauze cages measuring 9-in. × 9-in. × 9-in. The date of egg-laying was not recorded. The hoppers hatched out on 21st September 1932 and the hatching was a mixed one, consisting of fifteen green, ten intermediate and forty-three black hoppers. Only green hoppers were selected for this experiment. These hoppers belonging to a mixed hatching did not have the *solitaria* tendency of the hoppers in experiment I, but when bred in isolation developed marked *solitaria* coloration.

Conditions.—The hoppers were bred in isolation in an atmosphere containing excess of carbon dioxide.

Food.—Cotton leaves changed thrice a day.

The temperature of the rearing room during the experiment was :—

Highest maximum .	. 33·5°C.	Highest minimum .	. 29·2°C.
Lowest maximum .	. 29°C.	Lowest minimum .	. 25°C.
Average maximum	. 31·8°C.	Average minimum .	. 27·8°C.

Average mean temperature :—29·8°C.

C. Experiment III

History.—Reference No. P 53.

The solitary adults were collected from Pasni on 8th August 1932 and were received at Lyallpur on 17th August 1932. They were reared in wire-gauze cages measuring 9-in. × 9-in. × 9-in. The date of egg-laying was not recorded. Hatching was a mixed one, consisting of fifty-six green and five intermediate hoppers. Only green hoppers were taken for this experiment. Thus the *solitaria* tendency of these hoppers was less marked than that of the hoppers used in experiment I, but more than that in the hoppers in experiment II.

Conditions.—The green hoppers were isolated and bred in an atmosphere containing excess of carbon dioxide from 11th September 1932 onwards.

Food.—Cotton leaves changed three times a day.

Temperature of the laboratory during the experiment was :—

Highest maximum .	. 35°C.	Highest minimum .	. 30°C.
Lowest maximum .	. 29°C.	Lowest minimum .	. 25·5°C.
Average maximum	. 31·7°C.	Average minimum .	. 27·6°C.

Average mean temperature :—29·6°C.

D. Remarks on experiments, I, II and III

These experiments were conducted in a room where the temperature during the experiment varied from 25°C. to 35°C. and the mean average was approximately 30°C. This was the lowest temperature tried in this investigation. Thus, as expected, the intensity and extent of black pigmentation acquired by the hoppers in these experiments was the greatest. The progress of black pigmentation acquired from instar to instar by these isolated hoppers under the influence of carbon dioxide, as well as the state of coloration (from instar to instar) of isolated hoppers in the control, reared in an ordinary atmosphere is indicated in Table I.

TABLE I

Progress of pigmentation from stage to stage in hoppers in experiments, I, II and III

Experiment No.	Hatching	Details of experiment	Reference No.	I stage	II stage	III (*a*) stage	III (*b*) stage	IV stage	V stage
I	Pure green	Experimental hoppers bred in carbon dioxide atmosphere	P 54-57/CO_2 A .	Green type	Intermediate .	Intermediate .	Black type .	Strongly black type	Strongly black type
			Do. C .	Do. .	Green . .	Do. .	Do. .	Black type .	Black type
			Do. D	Do. .	Intermediate nearer green type	Intermediate nearer black type	Do. .	Do. .	Strongly black type
			Do. E .	Do. .	Intermediate nearer black type	Do. .	...	Do. .	Black type.
			Do. F	Do. .	Do. .	...	...	...	...
		Control hoppers	P54-57/Cont. 1.	Do. .	Green type .	Green type .	...	Green type .	Green type
			Do. 2 .	Do. .	Do. .	Do. .	...	Do. .	...
			Do. 4 .	Do. .	Do. .	Do. .	...	Do. .	Green type

| | | |

Experiment I was started with pure green hoppers of first stage, which were the progeny of '*solitaria*' parents. Whereas the control hoppers remained green throughout the hopper stages, all the hoppers reared in an atmosphere containing excess of carbon dioxide, with the exception of one (P 54-57/CO_2C), were intermediate, *i.e.*, showed some pigmentation, even after the first moult, *i.e.*, in the second stage. During the next stage they were all '*Black type*', and in the fourth and fifth stages all the surviving hoppers were '*Black type*'. Some of them had more intense and more extensive black pigmentation than a typical hopper in a crowded rearing at 30°C. and these forms have been described as "*Strongly black type*" (Plate LVIII, fig. 1). The duration of the life-cycle of these hoppers is given in Table II. All the hoppers in this experiment, which had survived, had an extra moult which we have called III-b*. None of the control hoppers had an extra moult.

TABLE II

Life-history of hoppers in experiment I

Reference No. P 54-57.

Room temperature { Average maximum 31·8°C. / Average minimum 27·7°C.

Days	Dates (1932)	Experimental					Control		
		A	C	D	E	F	1	2	4
1	14th Sept.	I	I	I	I	I	I	I	I
2	15th „ .								
3	16th „ .								
4	17th „ .								
5	18th „ .								
6	19th „ .	II		II		II	II	II	II
7	20th „ .		II		II	Died			
8	21st „ .								
9	22nd „ .								
10	23rd „ .								
11	24th „ .								
12	25th „ .								
13	26th „ .	III(*a*)			III (*a*)		III	III	III
14	27th „ .		III (*a*)	III (*a*)					
15	28th „ .								
16	29th „ .								
17	30th „ .								
18	1st Oct. .	III (*b*)	III (*b*)	III (*b*)					
19	2nd „ .				III (*b*)				
20	3rd „ .								
21	4th „ .								
22	5th „ .								
23	6th „ .		IV						
24	7th „ .			IV			IV		

* The extra instar is between the normal third and the normal fourth instars. The hopper approaches the fourth instar hopper in size, but resembles the third instar hopper in structure, notably the wing-pads.

TABLE II—*contd.*

Days	Dates (1932)	Experimental					Control		
		A	C	D	E	F	1	2	4
25	8th Oct. .								IV
26	9th „ .	IV			IV			IV	
27	10th „ .								
28	11th „ .								
29	12th „ .								
30	13th „ .								
31	14th „ .	V							
32	15th „ .						V	Died	V
33	16th „ .			V					
34	17th „ .								
35	18th „ .	V			V				

The hoppers in experiment II were 'green' hoppers from a mixed hatching which had a predominance of 'black' hoppers. The parents were '*solitaria*'. In this case all the control hoppers showed some gregaria tendency in II stage, but in all the subsequent hopper stages they were of '*Green type*'. The experimental hoppers in practically all cases acquired the extent and intensity of black pigmentation of '*Black type*' even in the II stage. During the subsequent stages they were, of course, '*Black type*' (Table I). The duration of their life-cycle is given in Table III.

TABLE III

Life-history of hoppers in experiment II

Reference No. P 55.

Room temperature { Average maximum 31·8°C. / Average minimum 27·8°C.

Days	Dates (1932)	Experimental					Control			
		A	B	C	D	E	F	G	H	K
1	21st Sept. .	I	I	I	I	I	I	I	I	I
2	22nd „ .									
3	23rd „ .									
4	24th „ .									
5	25th „ .									
6	26th „ .									
7	27th „ .	II	II	II	II				II	II
8	28th „ .						II			
9	29th „ .					II				
10	30th „ .	Died (Accident)						II		

TABLE III—*contd.*

Days	Dates (1932)	Experimental					Control			
		A	B	C	D	E	F	G	H	K
11	1st Oct.									
12	2nd ,,		III	III	III(*a*)				III	III
13	3rd ,,						III(*a*)			
14	4th ,,							III		
15	5th ,,									
16	6th ,,									
17	7th ,,									
18	8th ,,		IV							
19	9th ,,			IV			III*b*			IV
20	10th ,,									
21	11th ,,				III(*b*) Died	II Died	Died (Accident)			
22	12th ,,									
23	13th ,,									
24	14th ,,									IV
25	15th ,,									
26	16th ,,							IV		
27	17th ,,		V					(removed.)		
28	18th ,,									
29	19th ,,			V						V
30	20th ,,									

Experiment III was started with pure green hoppers which were selected from a mixed hatching having a predominance of '*Green type*'. The control hoppers remained green throughout their hopper stages, while the experimental hoppers manifested a marked approach to '*Black type*' even after the first moult. One of the hoppers, in the fourth stage and all the hoppers in the fifth stage were described as '*Strongly black type*' (Table I).

Mention may be made of the fact that occasionally, during these experiments, we had hoppers which had a deep brown pattern in place of the usual black pattern. These markings appeared as a diffuse pattern on a base of a lighter tint of the same colour, instead of a well-marked black pattern on a yellowish background (Plate LVIII, fig. 3). The hoppers of this type also occur in crowded rearings where the temperature is low and frequently falls below the developmental zero of the Desert Locust.

The duration of the life-cycle of the hoppers in experiment III is given in Table IV.

TABLE IV

Life-history of hoppers in experiment III

Room temperature { Average maximum 31·7°C. / Average minimum 27·67°C.

Days	Dates (1932)	Experimental		
		1	2	5
1	11th Sept.	I	I	I
2	12th ,,			
3	13th ,,			
4	14th ,,			
5	15th ,,	II	II	
6	16th ,,			II
7	17th ,,			
8	18th ,,			
9	19th ,,			
10	20th ,,	III(*a*)		
11	21st ,,			
12	22nd ,,			III
13	23rd ,,	III(*b*)		
14	24th ,,		III (*a*)	
15	25th ,,			
16	26th ,,			
17	27th ,,			
18	28th ,,		III (*b*)	
19	29th ,,	IV		
20	30th ,,			IV
21	1st Oct.			
22	2nd ,,			
23	3rd ,,			
24	4th ,,	V		
25	5th ,,		IV	
26	6th ,,			
27	7th ,,			V
28	8th ,,			
29	9th ,,			
30	10th ,,			
31	11th ,,			
32	12th ,,			
33	13th ,,		V	

To give an idea of the extent of pigmentation acquired under experimental condition in experiments I, II and III we give below a brief description of a representative fifth instar hopper, described in Table 1 as '*Black type*' :—

*E. Coloration of V stage hopper reared singly in an atmosphere of three per cent carbon dioxide at 30°C.** [Plate LVII].

(*i*) *General colour.*—Black predominates ; basic colour usually pale yellow.

(*ii*) *Head* : *Frons.*—Greenish yellow with fine black dots. Black at carinae.

Clypeus.—Ventral portion dull black, dorsally lighter.

Labrum.—Black.

Vertex.—Deep black on either side of the greyish epicranial suture. Deep black colour running down behind the eyes and joining the deep black sub-ocular genal stripe. Post-ocular area brown to black.

Gena.—Sub-ocular genal stripe deep black and broad. Area behind the stripe yellowish brown.

Antenna.—Black except lateral aspect which is brown.

Mandibles.—Black.

Maxillæ.—Dull white ; palpi black.

Labium.—Dull white ; palpi black ; galea black.

(*iii*) *Cervical sclerites.*—Black.

(*iv*) *Thorax* : *Pronotum.*—Basic colour greenish yellow or yellow ; white along the lower margin and the anterior and posterior margins ; anterior upper half margin often yellow ; keel white behind the post-sulcus and black in front. Entire area in front of anterior sulcus black with yellow specks. This black area runs downwards in front of the anterior sulcus and joins lateral black patch; lateral black patch extends from anterior margin to posterior margin behind and ventral margin below. The dorsal margin of this lateral pattern slanting from anterior sulcus to middle of the posterior margin. There is a black metazonal triangular area separated from the lateral pattern by a small area of pale yellow colour. The extent of this area varies.

Meso-episternum, *Meso-epimeron* } Yellowish brown, black along the margin.

Meta-episternum, *Meta-epimeron* } Black.

Sternum :—Dirty brown with numerous irregular black patches.

(*v*) *Leg* : *I and II pair.*—Dirty white with numerous smoky spots. Trochanter yellow. Femur yellow. Head of tibia and tarsi light brown. Claws brownish.

* For full description reference may be made to *Ind. J. Agric. Sci.* **6**: 624-64.

FIG. 1*b*. Abdominal segments III-V, lateral view.

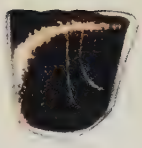


FIG. 1*a*. Pronotum, lateral view.

FIG. 1. II stage hopper reared isolated at 30°C. in excess of carbon dioxide.

FIG. 2*b*. Abdominal segments III-V, lateral view.

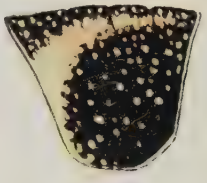
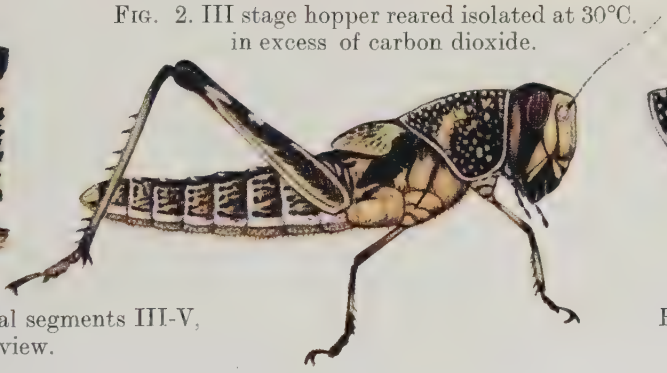


FIG. 2*a*. Pronotum, lateral view.

FIG. 2. III stage hopper reared isolated at 30°C. in excess of carbon dioxide.

FIG. 3*b*. Abdominal segments III-V, lateral view.



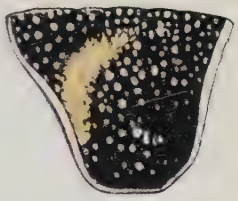


FIG. 3*a*. Pronotum, lateral view.

FIG. 3. IV stage hopper reared isolated at 30°C. in excess of carbon dioxide.

IG. 4*b*. Abdominal segments III-V, lateral view.

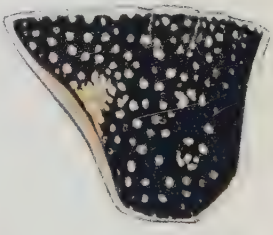


FIG. 4*a*. Pronotum, lateral view.

FIG. 4. V stage hopper reared isolated at 30°C. in excess of carbon dioxide.

III pair—hind femur.—Muscle-impression area from the head of femur to about 7/8 of its length black. Tibia-femur joint black. Spurs black. Tarsi black. Pads light brown. Tibia up to first spine of anterior row light black.

(*vi*) *Abdomen* : *Dorsal streak.*—Black with white triangular areas at the posterior margin of each segment.

Segment I.—Whitish all over.

Remaining segments.—Five black spots along the posterior margin, often fused with streaks in front. The lowermost of these spots fuses with a rather wide ventral straight streak ; in front of the third and fourth there are irregularly arranged spots. The fifth spot runs into the dorsal black streak.

Ventral side.—Yellow with many black dots.

It may be stated that at this temperature there appeared, now and then, some hoppers that had the patterns of brownish black colour with a sort of diffused coloration of a lighter hue (Plate LVIII, fig. 3).

When compared with hoppers bred crowded at 30°C. the pigmentation here is more intense as well as more extensive. The *Black type* representatives of II-V stages reared under these conditions are illustrated in Plate LVII, figs. 1-4.

F. Experiment IV

History.—Reference No. of parents : L 326.

The parents were laboratory bred and paired in the adult stage. The eggs were laid on 18th March 1933 and the hoppers hatched out on 5th April 1933. The hatching was a mixed one and consisted of thirty-eight green and four intermediate hoppers. The hoppers used in the experiment were green. Thus the '*solitaria*' tendency was of the same degree as in the hoppers in experiment III.

Conditions.—The experiment was started on 5th April 1933 at 40°C. in a thermostat. Two of the hoppers (N and P) were bred during the 1st stage under normal atmospheric condition at 40°C. and were transferred to the carbon dioxide atmosphere at the beginning of the second stage. The control hoppers were also reared at 40°C.

Remarks.—Taking into account the high temperature, the extent of black pigmentation in some cases was very marked indeed. The state of black pigmentation in V stage hopper described in Table V as *strongly black type* is illustrated in Plate LVIII, fig. 2.

TABLE V

Progress of pigmentation from stage to stage in hoppers in experiment IV

Reference No.		I stage	II stage	III(*a*) stage	III (*b*) stage	IV stage	V stage
A. L 326/5.IV.33	Experimental	Green type	Intermediate nearer black type	Intermediate nearer black type	Almost black type	Black type	Black type
F. Do.		Do.	Do.	Do.	Strongly black type	Strongly black type	Do.
H. Do.		Do.	Do.	Died	...	...	...
N. Do.		Do.	Green type *	Black type	Strongly black type	Died	...
P. Do.		Do.	Do. *	Green type	Do.	Black type	Almost black type
J.	Control.	Green type	Green type	Green type	Died	...	...
M.		Do.	Do.	Do.	Green type	Green type	...

* These hoppers were reared in ordinary atmosphere during their first instar.

Table V shows the progress of pigmentation acquired from stage to stage, and the duration of the life-history of the hoppers is given in Table VI. Below is given a brief description of a typical V stage hopper reared at 40°C. in an atmosphere containing three per cent carbon dioxide.

TABLE VI

Life-history of hoppers in experiment IV

Reference No. L.326. Temperature 40°C.

Days	Dates 1933	Experimental					Control	
		A	F	H	N	P	J	M
1	5th April .	I	I	I	I	I	I	I
2	6th „ .							
3	7th „ .							
4	8th „ .							
5	9th „ .							
6	10th „ .	II	II	II	II	II	II	II
7	11th „ .							
8	12th „ .			Died				
9	13th „ .		IIIa					
10	14th „ .				IIIa	IIIa	III	
11	15th „ .	IIIa	IIIb				Died	
12	16th „ .							
13	17th „ .							
14	18th „ .	IIIb			IIIb	IIIb		III
15	19th „ .							
16	20th „ .							
17	21st „ .		IV					
18	22nd „ .	IV						
19	23rd „ .							
20	24th „ .				IV	IV		
21	25th „ .				Died			IV
22	26th „ .							
23	27th „ .		V			V		Died
24	28th „ .	V						
25	29th „ .	Died						
26	30th „ .							

G. Coloration of a typical V stage hopper reared isolated in an atmosphere containing three per cent carbon dioxide at 40°C. [*Plate LVIII, Figs. 2, 2a, 2b*].

(*i*) *General colour.*—Black pattern less extensive but brighter than at 30°C. Ground colour bright yellow.

(*ii*) *Head : Frons.*—Yellow, a tinge of green at the frontal carinae.

Clypeus.—Dorsal half bright yellow, ventral half greyish yellow.

Labrum.—Yellowish in the middle, white at the margins.

Vertex.—Black on both sides of the greyish epicranial suture.

Gena.—Yellow and black ; sub-ocular genal stripe black and continued into the brownish narrow area running behind the compound eyes.

Post-gena.—Light brown to light black.

Antennae.—Basal five and distal five segments brownish, remaining segments dorsally smoky and ventrally brownish.

Mandibles.—Teeth black, exposed portion yellowish.

Maxillae, Labium.—Dull white with a tinge of yellow at places.

(*iii*) *Cervical sclerites.*—Strongly smoky.

(*iv*) *Thorax : Pronotum.*—Black with bright yellow dots. Ventral and posterior margins white and run into median metazonal line. Keel white in metazonal region, *i.e.*, behind the hind sulcus, yellow in front. Prozona black, with bright yellow dots. Greenish black patch on the lateral region at base of post-sulcus. Metazonal triangular patches light black with several yellow dots on each side of median line.

Meso-notum, Meta-notum.—Light black stripes on both sides of white median line. Below it brownish black stripes.

Meso-episternum, Meso-epimeron.—Yellow with black faint lines at the anterior margin.

Meta-episternum.—Yellow.

Meta-epimeron.—Yellow with anterior and posterior black margins.

Sternum.—Uniformly yellow.

(*v*) *Leg : I and II pair.*—Femur and tibia yellow. Tarsi light brown. Tips of claws dark brown.

III pair—hind femur.—A narrow black pattern on the muscle-impression area starting from the head of femur to 3/4 its length. Tibia-femur joints brown to black at places.

(*vi*) *Abdomen : I and II segments.*—Uniformly yellow ; no black markings.

FIG. 1*b*. Abdominal segments III-V, lateral view.

FIG. 1*a*. Pronotum, lateral view.

FIG. 1. V stage hopper, 'Strongly Black Type' at 30°C. in excess of carbon dioxide.

FIG. 2*b*. Abdominal segments III-V, lateral view.

FIG. 2*a*. Pronotum, lateral view.

FIG. 2. V stage hopper 'Strongly Black Type' at 40°C. in excess of carbon dioxide.

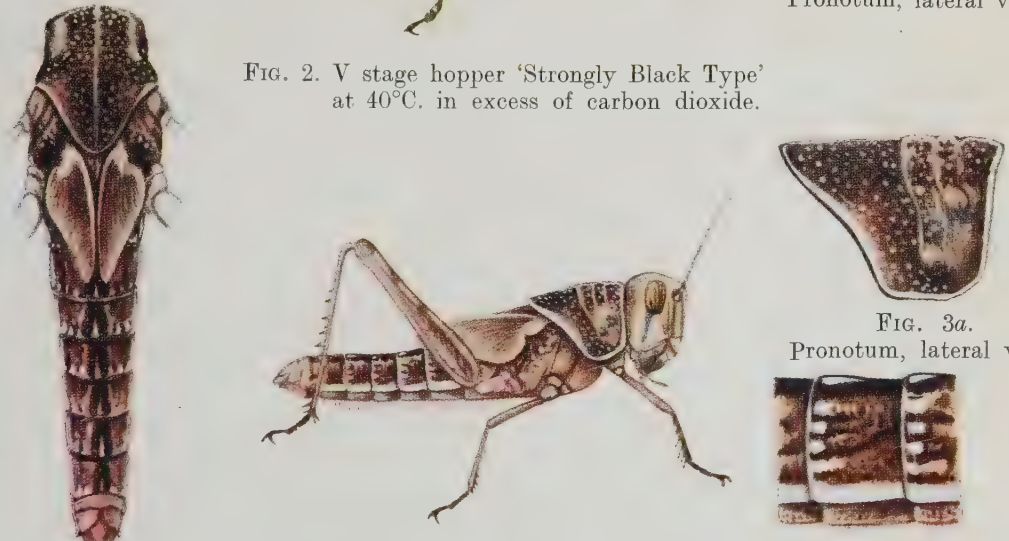


FIG. 3*c*. Thorax and abdomen, Dorsal view.

FIG. 3. V stage hopper reared at 30°C. in excess of carbon dioxide (special brownish colour).

FIG. 3*a*. Pronotum, lateral view.

FIG. 3*b*. Abdominal segments III-V, lateral view.

III to VIII segments.—Light black median dorsal streak with white triangular areas at posterior margin of each segment. Five black elongated dots at posterio-lateral margin of each tergum, ventral—most dot is united with narrow light black streak which is fainter anteriorly; in front of second dot a faint brown streak; opposite the third and fourth dots irregular small two or three dots; the fifth dot runs into narrow black dorsal streak.

IX segment.—A faint dorsal and a faint ventral streak.

X segment.—Uniformly yellow.

This colour approximates fairly closely with that of the hoppers bred crowded at 40°C. [*Cf.*—*Ind. J. Agric. Sci.* **6**, 624—64].

H. Experiment V

History.—Reference No. of parents: L 316.

The parents were laboratory bred and were paired in the adult stage.

The eggs were laid on 9th April 1933. The hoppers hatched out on 26th April 1933; the hatching was pure green and consisted of twenty hoppers. The experiment was conducted at 44°C. in a thermostat.

Remarks.—It is at this temperature, which is very near the upper vital limit for the hoppers of the Desert Locust, that a marked difference between the coloration of the hoppers bred crowded and those reared isolated in an atmosphere of three per cent carbon dioxide, occurred.

The hoppers reared crowded at 44°C., in an ordinary atmosphere, show no black pigmentation whatsoever [Husain and Ahmad, 1936]. They are generally white all over the body and it is only rarely that they have a tinge of yellow at places. But under the influence of three per cent carbon dioxide the black pigment appears (Plate LVIII, figs. 1—4). Even the ground colour, particularly in the advanced stages, is light yellow all over. The progress of pigmentation from instar to instar under these conditions is shown in Table VII and the duration of the life-history of these hoppers is given in Table VIII.

It is necessary to repeat once again that the term black type refers to the coloration developed in the hoppers bred crowded at 44°C.

TABLE VII

Progress of pigmentation from stage to stage in hoppers in experiment V

(Temperature 44°C.)

Reference No.	I stage	II stage	III stage	IV stage	V stage
A. L316/26. iv. 33	Green type	Intermediate nearer black type	Intermediate nearer black type	Black type	Back type
C. Do.	Do.	Intermediate	Do.	Intermediate nearer black type	Do.
F. Do.	Do.	Intermediate nearer black type	Black type	Do.	Intermediate nearer black type
H. Do.	Do.	Intermediate nearer green type	Intermediate nearer black type	Black type	Black type
J. Do.	Do.	Intermediate nearer black type	(*a*) Black type (*b*) Black type	Almost black type	Do.
L. Do.	Do.	Black type	..	Black type	..
M. Do.	Do.	Intermediate nearer black type	Black type	Do.	Black type

FIG. 1. II stage hopper reared isolated at 44°C. in excess of carbon dioxide.

FIG. 2. III stage hopper reared isolated at 44°C. in excess of carbon dioxide.

FIG. 3. IV stage hopper reared isolated at 44°C. in excess of carbon dioxide.

FIG. 4. V stage hopper reared isolated at 44°C. in excess of carbon dioxide.

I. The coloration of a typical V stage hopper reared isolated in atmosphere containing three per cent. carbon dioxide at 44°C. (Plate LIX, fig. 4).

(*i*) *General colour.*—Pale yellow all over with scanty deep brown to black pattern.

(*ii*) *Head : Frons.*—Uniformly pale yellow.

Clypeus and Labrum.—Whitish to grey.

Vertex.—Very light brown on both sides of the epicranial suture.

Gena.—Very light yellow. Sub-ocular genal stripe narrow and very light brown.

Post-gena.—Light yellow.

Compound eye.—Very light reddish brown stripes. Inter-stripe yellowish in the anterior half, whitish in the posterior half.

Antenna.—White with a tinge of yellow except the five basal segments which are whitish.

Mandibles, maxillae & labium.—Whitish to grey.

(*iii*) *Cervical sclerite.*—Whitish.

(*iv*) *Thorax : Pronotum.*—Brown patch on the ventral half of the pro- and meso-zonal region of the pronotum. Metazonal triangles deep brown to black but very small. Yellow dots on lighter yellow base all over the pronotum.

Wing-pads.—No black lines on veins or at base of the wing pads.

(*v*) *Legs : I and II pair.*—White.

III pair.—Femur with a narrow pattern consisting of black dots on muscle-impression areas and extending from head of femur to 3/5 its length. Rest of hind leg white.

(*vi*) *Abdomen : I and II segment.*—Uniformly white with a tinge of yellow.

Dorsal streak.—Dark brown and narrow with elongate white triangular areas at posterior margin of each abdominal segment.

Remaining segments.—Four to five small light black dots at the posterior lateral margin of each segment.

J. Experiment VI

History.—Reference No. of parents : P 136.

The solitary adults were received from Pasni on 8th July 1933. In the laboratory the adults were reared in pairs in cages measuring 6-in. × 6-in. × 12-in. The eggs were laid on 2nd August 1933. The hatching consisted of twenty-five green and fifteen intermediate hoppers. Only the green hoppers were selected

for the experiment. The '*solitaria*' tendency was the same as in the hoppers in experiment II. The temperature of the rearing room during the period was :—

Highest maximum . .	35·5°C.	Highest minimum . .	33·5°C.
Lowest maximum . .	30·0°C.	Lowest minimum . .	28·0°C.
Average maximum .	33·9°C.	Average minimum . .	31·8°C.

Average mean temperature—32·85°C.

The aim of this experiment was to determine the maximum concentration of carbon dioxide which *Schistocerca gregaria* hoppers could tolerate.

On 1st August 1932 ten freshly-emerged green hoppers selected from a mixed hatching were isolated and reared in an atmosphere containing about three per cent carbon dioxide. During the first instar two of these died, and the remainder had attained III instar by the 12th September and without exception showed that degree of black pigmentation which is typical of the crowded hoppers at 33°C. At 12 noon on the 12th September the discharge of carbon dioxide into the rearing jar was slightly increased. No marked result was observed till 10 o'clock on 14th September when the carbon dioxide discharge was further increased. At 3 P.M. on the same day six out of the eight hoppers were found dead while the remaining two were in a semi-concious condition and were breathing very fast. A sample of the air at this stage was taken two inches above the bottom of the jar (the position where the two hoppers which were still living were resting on the wire-gauze of the cage) and analysed. This was found to contain seven per cent of carbon dioxide at normal temperature and pressure (by volume). The two hoppers struggling for life were immediately removed from the jar and placed outside. They revived. From 15th September onward they were again subjected to three per cent carbon dioxide atmosphere and they successfully reached the adult stage. Seven per cent of carbon dioxide by volume in an atmosphere, therefore, is a little higher than the maximum concentration in which *Schistocerca gregaria* hoppers can live.

IV. Biometrics

In a number of Locusts it has been shown that besides coloration the difference in their two extreme forms, *i.e.*, phases *solitaria* and *gregaria*, is reflected in the relative size of certain parts. These characters are best expressed, among other things, in the ratio of elytra femur lengths, and, in the ratio of the width of pronotum to its length. As a rule, the ratio of the elytra length to the femur length in a '*solitaria*' adult is lower than that in a '*gregaria*' adult, also the pronotal proportion (width/length) is lower in *solitaria* than in *gregaria* adults.

Since black pigmentation can be acquired by an isolated hopper reared in an atmosphere of excess of carbon dioxide, it is not without interest to determine the influence of this factor on certain morphological characters. For this purpose we restricted our observations to the elytra : femur ratio.

Two sets of experiments were arranged, and the procedure adopted was as follows :—

The hoppers of a single pure green hatching were taken. They were divided into three batches . One batch was reared crowded in a cylindrical cage 8·5 inches high and 4·5 inches in diameter, and fresh leaves were supplied for feeding thrice a day. The hoppers of the other two batches were reared isolated in cylindrical wire-gauze cages six inches high and two inches in diameter. These were also supplied with fresh leaves thrice a day. One of these batches was bred in an ordinary atmosphere, while the other was reared in an atmosphere containing excess of carbon dioxide, which was approximately four per cent.

About twenty-four hours after the final moult the lengths of the right femurs and right elytrae of the adults were measured. The measurements were made by means of a fine pair of dividers and a Vernier scale (metric system). All the hoppers bred crowded and each one of the isolated hoppers bred in an atmosphere containing an excess of carbon dioxide showed patterns of the *black type* hoppers. The isolated hoppers were of the *green type* throughout the hopper stages.

Set I

History.—Reference No. of parents : P 136.

The parents were of the *solitaria* phase and were received from Pasni on 8th July 1933. They were reared as a pair in the laboratory, in a cage measuring 9-in. × 9-in. × 9-in. The date of egg laying was not recorded. The hoppers hatched out on 19th August 1933 and the hatching consisted of seventy-eight hoppers of *green type.*

Conditions.—The experiment was conducted inside the laboratory and the temperature during the period was :—

Highest maximum . .	32·2°C.	Highest minimum .	29·4°C.
Lowest maximum . .	27·7°C.	Lowest minimum . .	26·0°C.
Average maximum .	30·08°C.	Average minimum .	27·09°C.

Food.—Fresh cotton leaves were supplied three times a day.

The measurements of this set are :—

S. No.	Reference No.	Sex	Hind femur length (F)	Elytra length (E)	E:F	Range of E:F
	Isolated in ordinary atmosphere					
1	P136 / 19. VIII. '33 10	Male .	26	52	2·000	1·961—2·083
2	" 13	Male .	24	50	2·083	

S. No.	Reference No.		Sex	Hind femur length (F)	Elytra length (E)	E : F	Range of E : F
			Isolated in ordinary atmosphere—contd.				
3	P 136 / 19. VIII. '33	25	Male .	25	50	2·000	
4	,,	7	Male .	24·5	50·5	2·061	1·961—2·083
5	,,	9	Male .	26·0	51	1·961	
6	,,	14	Female .	28·4	56	1·975	
7	,,	16	Female .	29	57·8	1·993	
			Isolated in an atmosphere containing 4 per cent carbon dioxide				
1	P136 / 19. VIII. '33	(CO_2B)	Male .	23·5	46	1·957	
2	,,	(CO_2H)	Male .	25·2	50·2	1·992	
3	,,	(CO_2K)	Male .	24·8	50·1	2·020	
4	,,	(CO_2L)	Male .	27·7	55·3	1·996	1·938—2·037
5	,,	(CO_2A)	Female .	27	55	2·037	
6	,,	(CO_2D)	Female .	29	57·2	1·972	
7	,,	(CO_2E)	Female .	28·8	56·7	1·938	
			Crowded in ordinary atmosphere				
1	P136 / 19. VIII. '33	C1	Male .	23	49	2·130	
2	,,	C4	Male .	24	51·0	2·125	2·092—2·130
3	,,	C2	Female .	27	56·5	2·092	
4	,,	C3	Female .	26·8	57·0	2·126	

Set II

History.—Reference No. of parents : L 371.

The parents during their hopper stages were bred isolated and during the adult stage in a pair in a cage measuring 9-in. × 9-in. × 9-in.

The hoppers under experiment hatched out on 29th November 1933, the hatching consisting of sixty-two hoppers of the *green type*.

All the three batches of hoppers were reared in a wooden cabinet which was heated by means of electric lamps and was kept closed. The average temperature during the period was about 32°C. The humidity was high.

Food.—Fresh cotton leaves were supplied thrice a day.

The measurements are :—

S. No.	Reference No.		Sex	Length of hind femur (F)	Elytra length (E)	E : F	Range of E : F
			Isolated in ordinary atmosphere				
1	L371 / 29. IX. '33	33	Male	25·5	50·8	1·995	
2	,,	14	Male	26	51·2	1·969	
3	,,	16	Male	24·8	48·5	1·955	
4	,,	21	Male	25·0	51·5	2·060	
5	,,	17	Female	27·5	56	2·040	1·955—2·067
6	,,	8	Female	29·5	61	2·067	
7	,,	18	Female	30·2	60·1	1·990	
8	,,	12	Female	30	59·5	1·983	
9	,,	11	Female	24·2	48·2	1·991	
			Isolated in an atmosphere containig 4 per cent carbon dioxide				
1	L371 / 29. XI. '33	36	Male	25·8	49·2	1·907	
2	,,	6	Male	26·2	53·0	2·023	
3	,,	20	Male	25	51·1	2·044	
4	,,	26	Female	28·2	56·0	1·985	
5	,,	2	Female	26·8	53·5	1·996	1·907—2·098
6	,,	5	Female	29	61·5	2·120	(except L371 / 29.XI.33 5)
7	,,	23	Female	28·4	59·5	2·098	
8	,,	19	Female	27·0	56·5	2·092	
9	,,	30	Female	27	55·5	2·055	
			Crowded in ordinary atmosphere				
1	L371 / 29. XI. '33	A	Male	25·2	53·0	2·103	
2	,,	D	Male	25·8	53·2	2·062	
3	,,	F	Male	24·6	52·1	2·118	2·062—2·118
4	,,	B	Female	29·0	60·5	2·091	
5	,,	C	Female	27·8	Wing damaged		
6	,,	E	Female	28·4	59·6	2·099	

Table VIII shows the range and the mean value for the ratio E : F, arranged with reference to environment, sex and parentage. It would be seen that the range of the ratios for the isolated hoppers reared in the atmospheres of excess of carbon dioxide falls beyond the range of ratios obtained for the crowded hoppers but lies almost exactly within the range of ratios arrived at in the case of hoppers bred isolated in ordinary atmosphere.

TABLE VIII

Mean E : F with reference to environment, sex and percentage

Environment	Isolated ; atmospheric air		Isolated ; 4 per cent carbon dioxide in air		Crowded : atmospheric air	
Parents . . Sex	P136	L371	P136	L371	P136	L371
Male . .	2·007 (3)	1·994 (4)	1·491 (4)	1·991 (3)	2·125 (2)	2·094 (3)
Female .	1·984 (2)	2·014 (5)	1·982 (3)	2·057 (6)	2·108 (2)	2·095 (2)
Mean . .	1·999 (14)		2·005 (16)		2·105 (9)	
Ranges .	1·961—2·083	1·955—2·067	1·938—2·037	1·907—2·098	2·092—2·130	2·062—2·118

Thus while a hopper reared isolated in an atmosphere containing an excess of carbon dioxide resembles a crowded hopper in the development of black pigmentation, it approaches the hoppers reared isolated, in ordinary atmosphere with regards to its elytra : femur ratio. Further it appears that while in nature the black pigmentation and the higher elytra : femur ratio occur together, these characters may not necessarily always go together. Indirectly our experiment also indicates that whereas the body proportions are dependent on the nature of life lived by the hopper (active or sedentary), the development of black pigmentation may be determined by certain other factors, which may or may not be related to the mode of life of the insect.

V. DISCUSSION

These experiments very clearly show that a green *solitaria* hopper, which, if reared isolated in an ordinary atmosphere, would have retained *solitaria* green coloration, acquired the *gregaria* coloration *i.e.*, black pigmentation, when reared in an atmosphere containing an excess of carbon dioxide. Further the extent and intensity of black pigmentation of these hoppers depends as much on temperature as it does in the case of hoppers bred crowded [Husain and Ahmad, 1936]. Having established this one naturally asks : Is the concentration of carbon dioxide in the atmosphere surrounding the swarming crowded hoppers high enough to induce pigmentation ?

It may be stated that if only two hoppers of the non-swarming type, are reared in a cage measuring 9-in. ×9-in. ×9-in. and covered on five sides with wire gauze of 16 meshes to an inch, they acquire black coloration typical of the swarming type. Under these conditions the percentage of carbon dioxide in the cage cannot be appreciably higher than that in the atmosphere outside the cage. Nor would

the hoppers be always so close together as to inhale any substantial amount of the air exhaled by the other. Therefore the pigmentation in the two hoppers can not be said to have been produced by any excess of carbon dioxide inhaled.

However, it cannot be denied that in a swarm the air immediately around the hoppers will have a higher concentration of carbon dioxide than in an ordinary atmosphere, and also that the air inhaled by the hoppers in a swarm in most cases will contain a large proportion of the carbon dioxide expired by their compatriots. Whilst the carbon dioxide thus inhaled may be playing a significant role in the production of black pigment, it cannot be said that in all cases the excess of carbon dioxide inhaled is the only cause of the development of *gregaria* coloration.

Faure [1932] had advanced a theory, of ' locustine ' production, to explain the development of *gregaria* coloration in swarming hoppers. His explanation is that ' as the result of the excessively high rate of metabolism obtaining in swarm life, the muscles and other tissues produce a surfeit of excretory products that cannot be disposed of by the Malpighian tubules, and these—or their derivatives—are desposited in the cuticula in the form of a definite pattern of black pigment '. These products of excessive metabolism he designates 'locustine '. In the experiments conducted by us the hoppers were isolated in limited space, therefore, the question of the production of a surfeit of excretory products through excessive rate of metabolism that cannot be disposed of by the Malpighian tubules does not arise. It would, however, appear that the production of the *gregaria* coloration is perhaps connected, among other factors, with the respiratory functions of the organism.

It is well known that the hoppers, soon after hatching, manifest coloration characteristic of the phases. In other words they may be black *i.e.*, having coloration of the swarming phase, or green *i.e.*, possess coloration of the *solitary* phase, or they may even be intermediate, *i.e.*, show patterns which are less intense in pigmentation. As a rule the progeny of the *solitaria* parents is green, with no black pigmentation, while that of the swarming parents is black *i.e.*, possesses *gregaria* coloration. Faure explains this phenomenon by saying that " the blood and tissue of the *gregaria* females being more or less saturated with locustine the nutritive yolk of the eggs must also receive it ". Further that " during its development the embryo digests the yolk, and the locustine finds its way into the cuticula to produce the black characteristics of the first instar ". It is well known that quite frequently the hoppers emerging from the same batch of eggs are not all of the same colour, some may be of *green type* while others *black type*. This discriminate distribution of locustine it is difficult to explain.

VI. Summary

1. An excess of carbon dioxide in the atmosphere produces in isolated hoppers black pattern of the type found in swarming hoppers.

2. The black pattern in its intensity and extent is governed by temperature in the same manner as in the crowded hoppers.

3. These hoppers in spite of the production of the black pattern retain in them the *solitaria* body-proportion.

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THE LOCUST INCURSION OF 1935 IN NORTH-WEST INDIA—ITS SIGNIFICANCE IN THE STUDY OF THE LOCUST PROBLEM

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(With two maps and one text-figure)

Introductory

During the last locust cycle of 1926-1931, the Desert Locust (*Schistocerca gregaria* Forsk) was active in most of the districts of North-West India either in spring, summer or autumn, and caused a great deal of damage to cultivation. A great mass of data in regard to the details of its activities during this period has been gathered from various sources, chiefly from reports received by the Revenue Departments of the various Provinces and States of North-West India. The material thus accumulated is now under detailed examination. A cursory study of the locust data, however, has shown that in the Indo-Iranian area of infestation, *Schistocerca* breeds in spring in regions subject to winter-rainfall, such as Iran, Baluchistan and parts of the Punjab. The adults of the generation developing from this spring brood are ready to fly between April and June. Beginning from May or June, however, the vast region extending from Dasht-i-Lut and Seistan in Iran to Chagai, Kharan and Panjgur in Baluchistan becomes an area of high temperatures and low humidity with hot, scorching winds blowing from a northern or north-western direction. Locusts produced in the interior of Baluchistan fly out of this area, either south towards the Mekran coast or east towards Sind, Rajputana, Punjab and the United Provinces, their flights being apparently influenced in the latter case by the prevailing south-west winds. As these areas are subject to summer or monsoon rainfall, swarms breed here between June and September, and the summer brood is ready to take to flight by October-November. At this time of the year, the desert areas of Rajputana become a zone of low humidity, which apparently locusts seem to flee from, their flights being directed either

eastwards into the United Provinces and Bengal, or southwards into Central India or the Bombay Presidency, or westwards into Sind, Baluchistan and Iran. These flights are composed of young pink locusts, which may prove very destructive to cultivated crops and to general vegetation. In the case of the westward movements, the swarms show their greatest activity during the months of October and November, when their flights are greatly helped by the prevalent north-east wind. As the cold season advances, the flight movements are greatly retarded, and the swarms usually break up, the individuals getting scattered and passing the winter in a more or less inactive condition in suitable localities. When the weather warms up again with the advent of spring, the over-wintered locusts presumably gather again into swarms. The phenomenon of over-wintering appears to occur wherever swarms happen to be overtaken during their flights by spells of cold weather, and records of the wholesale destruction of swarms in the past in the winter in the uplands of Baluchistan indicate that it is only in the warmer valleys of southern Baluchistan and along the coast that locusts have the greatest chances of surviving the winter.

In the course of a study of the records of locust movements during the last cycle, it has been found that the details of flights are often very meagre, and in certain cases the indicated directions are so confusing that it is difficult to correlate them with other data. On the whole, however, the movements are distinguishable into two principal categories, *viz.*, (1) local movements, in which no unified general direction is discernible, and which are generally associated with a search for forage or for places suitable for egg-laying and (2) mass movements of swarms, associated with a change of the seasons, and characterised by a certain regularity of appearance at particular times of the year and also by a general uniformity of direction. Although it is in general impossible to trace the movements of particular swarms from place to place on account of the imperfections of the recorded reports, it has been actually found possible to follow the progress of a few to a certain extent.

In regard to Sind and Baluchistan, it may be stated that the new swarms of the year always make their entry from a western direction during May, June or July, the first reports being received from the westernmost points, as for example, Bhag and Gandhawa for Kachhi, Dadu, Johi and Shikarpur for Sind, and Jaisalmer and Khairpur areas for the Rajputana desert, and in the course of a few days the further progress of the swarms can usually be traced eastwards. On the other hand, the first swarms of the autumn reach the Baluchistan borders from an eastern direction during October every year.

The locust incursion of 1935

Since December, 1931, locust swarms have ceased to make their periodic appearance in Sind, Baluchistan and Rajputana, and except for a few cases

reported in the cold weather of 1933-34 from the borders of the Rajputana area, no large swarms have been recorded.

Though in the course of surveys made by the Locust staff in the desert areas of Baluchistan and Rajputana, specimens of the non-gregarious, solitary type of locusts had been found in various localities in varying numbers during the last four years, no large concentrations had so far been noted anywhere. The reported appearance, therefore, of a swarm on the 1st July at Shahgarh in Jaisalmer, of another at Reti on the 4th July along the borders of Jaisalmer and Bahawalpore states, and of two other swarms on the 19th and the 29th July respectively in the Khairpore state indicated that, perhaps, a new locust cycle had possibly begun. In addition, the Locust Survey staff had detected a sudden increase of locust population in mid-July in widely separated areas, such as the coastal tracts of Mekran, the Lasbela State, the Kachhi area, the western talukas of Sind, such as Sehwan, Dadu, Johi and Thano Bulakhan, parts of Thar-Parkar and Hyderabad districts, and the desert areas of Jaisalmer, Jodhpur and Bikaner States. At Pasni, where the population rate of locusts on the *rek* areas during the first week of July was only about 500 per sq. mile, the density showed a sudden rise to about 5,000 per sq. mile after the 12th July, and a few weeks later reached about 40,000 per sq. mile. A great many of the locusts noted in July after such increase were, moreover, pinkish in colour, while a certain proportion was bright yellow, and a biometrical examination revealed the existence of *gregaria* ratios in many of them. On the other hand, the comparatively small population existent prior to the 12th July were mostly characterised by the possession of the colour pattern of typical *solitaria* and of ratios of the solitary or intermediate types.

It was evident, therefore, that an incursion of locusts on a large scale had taken place, bringing about the entry of large numbers of specimens of a type approximating the *gregarious* into the Sind-Rajputana area, somewhat in the same manner as if a migration of the usual type in swarm formation had occurred. As the invasion had taken place at a time when the monsoon was beginning to be active in the desert areas, it was feared that a multiplication of the locust in the summer rain areas might inaugurate a new cycle of infestation in the Indo-Iranian area.

The locust incursion of 1935 is remarkable in two ways. First, although in the aggregate a very large number of locust individuals had evidently participated in the incursion, the migration did not take the form of a mass movement of swarms, which one usually associates with a locust invasion. It had, on the other hand, occurred in the form of an imperceptible migration of individuals. This raises the general question of whether the *solitaria* individual is capable of undertaking long distance migrations. As several interesting observations have been made on

this subject during 1935, it is proposed to discuss this subject in greater detail. Secondly, as neither the existence of swarms in Baluchistan nor their entry from outside from neighbouring areas such as Iran had been reported, the migrants of July 1935 could not have originated from swarms. Should this view be correct, their origin could only have been due to a local transformation of the phase *solitaria* into *gregaria*. In other words, local outbreak centres must have come into existence during the year in Baluchistan. As three cases of incipient swarming had come to light during the year, the question will be discussed and its bearing on the subject of control considered.

Migration among the solitaries

The natural habitat of the solitary phase in the Indian area

Although swarms had vanished since December 1931 and locust specimens were not to be seen in most parts of North-West India, solitary specimens were being noticed in greater or smaller numbers in many of the desert areas of Sind, Baluchistan, Rajputana and South-West Punjab by the Locust Survey staff during the years 1932, 1933 and 1934. In many cases, however, the presence of the locust at any particular place was found to be governed by the factor of seasonal distribution. Though, for instance, found in good numbers in the rainy season, they were noticed, with the advent of dry weather to have either completely disappeared or to have become considerably diminished in numbers. On the whole, the preferred habitat of the solitary form of *Schistocerca* was observed to be a sandy area covered with a fair amount of perennial scrub vegetation. Along the Mekran Coast, numerous undulating patches of sand, known locally as '*reks*' are found stretching along the sea-beach, as at Sonmiani, Ormara, Kalmat, Pasni and Gwadar. Originally formed of drifting mounds of sand blown by the sturdy south-west wind from the sea-beach into the interior, they have now become covered over by a scrub vegetation of varying density, which affords both food and shelter to the solitary locust. In the Rajputana area, the vast region of the Indian Desert extending from the shores of the Runn of Cutch for over 600 miles of country up to the borders of the Hissar District, forms another of the favoured habitats of the locust. Being subject to heavier rainfall, the vegetation of the Indian Desert is of a more luxuriant character, and the cover is, on the whole, very much denser, being composed of taller bushes than those on the western '*reks*'. In the desert area the atmosphere is usually drier except during the rains, and the fluctuation of diurnal and annual temperature is greater than in the '*rek*' areas, which being subject to the tempering influence of the sea, are characterised by a fairly humid atmosphere and more equable temperature conditions.

As in the case of the phase *gregaria*, the phase *solitaria* also needs a fairly moist sandy soil for oviposition, and under natural conditions a moist soil would be obtainable only after sufficient rainfall. Consequently the breeding of the solitary phase locust is entirely dependent on the character of the seasonal precipitation.

The western '*reks*' of Mekran fall within the zone of winter rains, the precipitation occurring usually between December and April during the passage of a series of shallow winter disturbances which, starting from the Syrian coast of the Mediterranean Sea, rapidly march eastwards over Iraq, Iran, Baluchistan and Northern India up to the Himalayan Range. On the other hand, the eastern '*reks*' situated in Lasbela State as well as the Indian Desert areas come under the influence of the Indian monsoon, and the rainfall occurs mainly in the summer season between June and September. It, therefore, follows naturally that the locust can breed, in the western areas, only during the winter or spring months usually between February and May, while in the summer rainfall areas, *e.g.*, Lasbela and Rajputana, breeding usually occurs between July and September. During years of drought, breeding may be entirely absent, as had happened at Pasni, Gwadar and Ormara throughout the year 1934, and in the Lasbela area during 1935.

Methods of locust-surveys adopted

During 1931, a rapid preliminary survey of the various parts of Baluchistan was made, chiefly with the object of finding if any permanent breeding areas of the *solitary* phase were existent in that country. As it was found that it was only in Southern Baluchistan that conditions favourable for the breeding and continued existence of the *solitary* locust were existent, a station for studying the life-habits and ecology of the *solitary* phase in its natural breeding grounds was opened at Pasni in January, 1932, and continued observations made during the last four years have proved to be of great value in the investigation of the Locust problem.

One of the points to which particular attention was paid was a study of the fluctuations of the local locust population by conducting periodical surveys in the different areas of the Pasni *reks*. Special attention was paid during the breeding season in regard to making an estimate of the hopper population. The presence of hoppers was detected on the bushes by delicately tapping the branches with a light rod and counting the hoppers found within a particular area. In the case of the adults, it was observed that they do not usually seek the shelter of bushes unless the sand-surface temperature is abnormally high, or the weather too windy, and as a rule, they generally prefer to sit on the surface of open patches of sand. Even in winter, they are so easily started when the sun has warmed up

the atmosphere, that there is little need for beating the bushes. For estimating the population, therefore, the surveyor can easily make a count of locusts, flying up on either side, as he proceeds slowly forward. It has been found that in warm weather a single surveyor can, in this way, efficiently cover a distance of eleven feet on either side, carrying a stick in his hand. Surveys are generally made on foot, and usually a party of four to six men walk abreast of one another at a distance varying from fifteen to twenty feet and march as far as possible straight ahead. At the end of the day's survey, the approximate total distance covered by each man is calculated (with the aid of a pedometer where available) and the number of specimens observed by each man noted. The total area covered by the party during the day is computed in square miles by multiplying the distance covered (in miles) with the total breadth (in fractions of a mile) covered by all the surveyors, *i.e.*, (22 ft. ÷ 5,280 ft.) × the number of surveyors. The area covered being thus obtained in square miles, the rate of population per sq. mile is capable of being readily worked out.

In the Lasbela area, which is important on account of the reason that it is one of the summer breeding areas of the locust, rather desultory surveys were being carried out by a Fieldman stationed at Sonmiani since February 1932, but from June, 1933 a regular station was opened at Ambagh in the neighbourhood of Sonmiani and intensive surveys were thenceforth carried out. Two observation posts were opened, (1) at Chachro in the Thar-Parkar District in the Sind Desert and (2) at Sardarshahr in the Bikaner State in 1934 for the purpose of intensive survey work, and two more at (1) Nokh in the Jaisalmer State and (2) at Barmer in the Jodhpur State during 1935. On account of the continuity and intensiveness of the observations made at such typical centres of the different regions of locust habitat, results of great value have been obtained.

Fluctuation of locust population at Pasni and Ambagh during the last four years

Fairly comparable figures in regard to the relative density of population have been calculated from the results of periodical surveys made at Pasni and Ambagh since July, 1933, but prior to this period, the figures are not satisfactory, and information is completely lacking for certain months of 1932. With the available data, the mean monthly population rate during successive months was worked out as far as possible and shown in the attached graph (Fig. 1). The periods during which local breeding actually occurred have been marked on the graph, as also those during which an influx of population from outside was either known to have occurred or was suspected.

1932
1933
1934
1935
FLUCTUATION OF LOCUST POPULATION ON THE PASNI REKS 1932 TO 1935
FLUCTUATION OF LOCUST POPULATION ON AMBAGH-SONMIANI REKS 1932 TO 1935
MEAN RATE OF POPULATION PER SQ. MILE.
RISE DUE TO APPEARANCE OF MIGRANTS
PERIOD OF LOCAL BREEDING
BREEDING

Fig. 1.

From the graph, it is evident that both at Pasni and Ambagh, a considerable fluctuation of population had been occurring every year, obviously as the result of more than one factor. First, there is the factor of local breeding as a result of which a rise is noticeable at the close of the breeding season, both at Pasni and Ambagh. At Pasni this is followed, especially in 1933 and 1935, by a rather sudden fall of population, which it would be rather difficult to account for, if our concept be that of a purely local, static population ; for the diminution in numbers is so disproportionately large that it cannot be referred solely to the factor of natural enemies. Contrary to expectation, a distinct rise in population is noticeable at Pasni during May-June 1932, during July-August 1935, and to a slight extent also in May and July 1934, none of these cases being connected with local breeding. Specimens collected at these periods have, moreover, shown fairly high elytron-femur ratios ranging from 2·10 to 2·30. In 1932 and 1935, moreover, the increase of population was definitely known to be due to a general influx of forms of pink, yellow and grey colour from outside.

At Ambagh, an increase in numbers rather out of proportion to the extent and duration of local breeding is noticeable during the months of October and November in 1933 and 1934, and possibly also in 1932. A similar increase is found to have occurred in October and November 1935, in spite of the absence of local multiplication, and in this case, the influx of a recently developed brood of locusts of rather low elytron/femur ratios was definitely established. A similar influx of forms appears to have occurred also at Pasni in October-November 1933, in December 1934 and in November 1935.

In 1935, few locusts are noticeable at Ambagh between January and May, but during June a sudden influx of specimens of a recently developed brood, showing ratios of the solitary phase, was noted. A similar rise in population is noticeable in 1933 and 1934 during the months of May, June and July.

The results of locust-survey work in 1935

During 1935, intensive survey work was in progress in the following places : Gwadar, Pasni and Ambagh in Baluchistan ; at Chachro in Sind ; and at Barmer, Nokh and Sardarshahr in the Rajputana Desert areas. In addition, periodical extensive surveys were also carried out throughout the year in the following parts of (1) *Mekran* : Gwadar-Pishukan-Suntsar ; Dasht-Kulanch ; Kech-Kolwa-Panjgur ; and Kalmat-Ormara ; (2) *Lasbela* : Pohr-Hingol-Uthal ; Hinidan-Shah Bilawal ; (3) *Sind* : Thar-Parkar Desert ; and (4) *Rajputana Desert area* : Mallani-Sheo-Mayajlar ; East Jaisalmer ; Bikaner.

The results of locust findings by the survey staff in all these areas have been marked in the accompanying two maps : Map I, depicting the locust situation during the first seven months from December 1934 to June 1935, and Map II, the situation during the five months—July to November 1935.

Map I : December 1934 to June 1935.—Except for the record of a few locusts noted in June 1935 and of a few stray locusts in Jaisalmer and Bikaner in February-March, locust findings are almost blank for the summer rainfall areas of Lasbela, Sind and Rajputana. On the western *reks*, on the other hand, locusts are seen to be present in abundance. Consequent on the occurrence of heavy winter rainfall, locust breeding was in progress during February, March and April in many places in Mekran both along the coast and in the interior. Adults of the new generation began to appear from the first week of April, and hoppers of the second generation were noted in May-June in Kulanch, Kech and Panjgur.

Map II : July-November 1935.—The situation is vastly different. Very few locusts are seen in the interior of Mekran after July, and the bulk of the locust population is seen to have shifted to the Rajputana desert areas. Early in July, a few swarms were seen in Jaisalmer and Bahawalpore areas, and a few about the middle of July in the Khairpore area. In addition, quite large numbers of locusts including a large proportion of pink and yellow forms appeared in various parts of North-West India : Kachhi, parts of Sind, Marwar, Jaisalmer and Bikaner, and also in the coastal areas of Mekran, in Lasbela and in parts of Karachi District.

In July-August, a fair amount of breeding was noted in various parts of the desert : Thar-Parkar, Mallani and Sheo *parganas* in Jodhpur ; and parts of Jaisalmer and Bikaner. There was no breeding in Mekran and Lasbela. In September-October a few hoppers were still to be found in parts of Thar-Parkar and Mallani, probably representing the second generation of the season.

By November, locusts had in great part disappeared from Bikaner, Jaisalmer and Marwar ; and at the same time, specimens of a new generation of locusts with hyaline or mauve wings were noted appearing in the *reks* of Ambagh, Hingol, Ormara and Pasni.

As already remarked, one of the notable features of the situation during the first half of 1935 was the almost complete absence of locusts in the Lasbela and Sind-Rajputana areas and their presence in the Mekran coastal *reks*. A somewhat similar disappearance was observed in the Thar-Parkar area during the earlier months of the year 1933 and 1934, and their absence was then attributed to the effect of either cold or drought causing them to hide themselves among the vegetation while the cold weather and the drought lasted. In order to test the validity of this assumption, a thorough examination of hundreds of bushes was made during January, February and March in a number of places such as Ambagh, Chachro Derawar, etc. The bushes were uprooted and all likely situations such as their bases and the soil below including the rat-holes were searched, but without finding any locusts in hiding. At Chachro, large thickets of thorn (mostly *Zizyphus* branches) used for fencing fields of cultivation were also lifted up and searched, and though large Acridids like *Anacridium* and *Crytacanthacris* were found taking shelter under them, no specimens of *Schistocerca* were seen. It may, therefore, be taken as proved that the disappearance of the locust from the Ambagh and

Chachro areas during the earlier months of the year was a positive fact, possibly due to seasonal emigration; and consequently the re-appearance of locusts in increasingly large numbers from May onwards at Ambagh and Chachro can only be explained as an immigration from outside.

A biometrical study of locust populations

When a sudden increase in the numbers of locusts was noted at Pasni about the 12th July 1935, a sample collection of the locust population was made and subjected to a cursory biometrical examination, when the existence of a fairly high proportion of forms possessing elytron/femur ratios of the *gregaria* type was detected. Subsequently, an examination of the locust collections on the *reks* at Pasni and elsewhere during the different months of the year 1935 was carried out as far as possible. Later on, all available specimens collected in 1934 were similarly examined biometrically. The results obtained have been tabulated and shown in Appendices I and II respectively. It may be added that in the biometrical studies made, only elytron/femur ratios have been taken into account. No attempts were made to calculate the mean ratios for the different months as the number of specimens available was not sufficiently high.

The results show that the initial population in January on the Pasni *reks* had mostly ratios of the *solitaria* type, and that the progeny of these locusts appearing in April and May also exhibited a dominance of *solitaria* ratios. The July immigrants which swamped the 'native' locust population, however, brought about a preponderance of '*transiens*' ratios with a good proportion of the *gregaria* type. These biometrical characteristics marked the locust population at Pasni till the end of October, even though their numbers had by then greatly diminished. In November, however, an ascendancy of the *solitaria* ratios was again noticeable.

The year 1934 was an abnormal one at Pasni, during which local breeding was completely absent on account of lack of rainfall, and the limited collection of preserved specimens available for examination forms too scanty a material to furnish a basis for any generalisations. Indications, however, are clear that an influx of *gregaria* forms had taken place in May-July, and that an immigration of *solitaria* type had also occurred at the end of the year.

Powers of high flying among the solitaries

When pursued, the *solitaria* adult usually makes only short flights covering not more than a few yards at a time, but its ability sometimes to rise high into the air and vanish out of sight has been noted by the locust survey staff at different times. The significance of this phenomenon was, however, not realised till the event of the July incursion. The fact that the locust population had perceptibly increased by the 12th July and that it included numerous specimens of pink and yellow forms, not known to have been present at Pasni prior to that date, clearly showed that the accretion of population was due to a migration from outside.

Since the arrival of a swarm from outside had not been noticed anywhere round-about Pasni, the inference would appear to be that the migration had been accomplished in the form of individual flights.

After the incursion had taken place, numerous instances of high flying were noted at Pasni. In many instances, locusts were observed to rise high into the air at dusk at an air temperature of 80 to 82° F. (about 27°C.) often without any apparent provocation, and disappear from sight. On some occasions, such high flights were also noted at mid-day. The height attained by the locust could not be accurately estimated, but it must have been at least 500 ft. above the level of the ground. The course of the flight was generally governed by the direction of the prevailing wind, but it was also clear that the locusts did not drift passively with the current, each individual being noted steering its course in a particular way. There is apparently little doubt that the long distance migration of the *solitaria* individual is greatly dependent on the strength and direction of the wind currents prevailing at the time. Since, however, the winds at different levels of the upper air exhibit different directional trends, it is rather difficult to attempt to trace the origin of locust migrants with the help of recorded data on surface currents.

In a few instances, individuals of the locust that were being observed ascending steadily higher and higher into the sky, were found for some unaccountable reason to change their minds, and, after closing their wings, to volplane down to the ground with the speed of a rocket. The swiftness and suddenness of the descent points to the difficulty in noting the actual arrival of the individual migrants, even if it should happen in broad day-light.

Experiments with the marking of locusts

Since February 1935, a system of marking locusts collected during the periodical surveys and liberating them was tried at Pasni with the object of making observations on their powers of movements from place to place. At first, marks indicating the month of liberation were made with cellulose paints on the pronotum of the locusts, but it was found that the paint peeled off after some time. Later on, painting the hind wings was tried, and even in this case there was a similar result, if the paint were applied thick. At present, a system of lightly painting the figure of the month in arabic numerals on the wings is in practice at Pasni. In order to signify the time of liberation more exactly, the left wing is painted during the first fortnight of the month, and the right wing during the second. In addition, a bit of coloured silk thread is tied at the distal end of the femora in order to facilitate their being spotted easily in the field. A similar system is being adopted, as far as possible, at Ambagh and the various Desert Outposts, different colours being adopted by each station : for example blue for Pasni, red for Ambagh, green for Chachro, and so on. The cellulose paints could

not, unfortunately, be obtained early enough for trying the system on an extensive scale during 1935.

Although marking of locusts has been under trial at Pasni since February 1935, it is only in three instances that recoveries have been recorded. (1) A locust painted white in February was captured in March not far off from the place of liberation on the Pasni *rek*. (2) A locust painted red on the hind wing and liberated early in May was found by the Ormara Fieldman at Rumra about twenty miles to the north-east from Pasni on the 17th May. (3) A locust painted blue on the hind wing and let off in June was found within a furlong of the Locust Camp early in July. The second case appears to be very significant.

Liberation was also tried at the following places in 1935 :—

	Month	No. liberated	Results
1. Barmer . .	Sept. .	45 locusts .	None recovered.
	Oct. .	40 locusts .	None recovered.
	Nov. .	15 locusts .	None recovered.
2. Nokh . .	Oct. .	30 locusts .	None recovered.
3. Chachro . .	Sept. .	10 locusts .	None recovered.
	Oct. .	18 locusts .	None recovered
	Nov. .	19 locusts .	Out of specimens liberated during the second fortnight of November, 1935 the following were recovered from the vicinity of Chachro on the dates indicated : 1. on the 5th December 1935 2. on the 30th December, 1935 and 3. on the 8th March, 1936 (in the last case, 3½ months after liberation).

More intensive efforts at the liberation and recovery of marked locusts may be productive of valuable results. Attempts at trying a system of offering rewards for the recovery of marked specimens may perhaps be made, but owing to the sparseness of the population and the difficulty of spotting out the non-gregarious type of the locust by the people, one cannot be over-sanguine about the results.

Summing up of the evidence

Reviewing the results of observations made during the last four years, it may be stated that a considerable volume of evidence has accumulated in regard to the existence among the non-gregarious type of locusts of powers of migration somewhat similar to those exhibited by the *gregaria* forms during years of infestation. Although the data of previous years had vaguely suggested the probability of the occurrence of migration covering short distances on the part of the *solitary* locusts there was no definite evidence in the matter. The results obtained during the year 1935, and especially the observations made at the time of the locust

incursion in July, have served to give fairly clear indications as to the capability of *Schistocerca* to migrate to a distant area by the flight of individuals as contrasted with a migration of swarms. Indeed, although a fairly large increase of locust population had taken place during July in quite a large number of places in Sind, Rajputana and Baluchistan, the fact was not noticed by the local inhabitants in many places, and in all probability the event might have remained unnoticed, had it not been for the activities of the Locust Survey staff stationed in the areas concerned.

The data collected on the subject may be classified under (1) Inductional evidence and (2) Direct evidence.

1. Inductional evidence

(*a*) *Fluctuation of population at Ambagh and Pasni, 1932 to 1935.*—A study of the data collected shows that the fluctuation in the density of population may be quite considerable during a year. If the locust population had been static for each individual breeding ground, the rise and fall in the numbers of locusts should have been capable of correlation with local breeding and climatic conditions. On the other hand, an increase in numbers sometimes occurs prior to the breeding season, and sometimes after the local breeding is over. The details of fluctuation are not explainable except on the basis of the possibility of seasonal migration, leading sometimes to an exchange of population between different breeding grounds and sometimes to an incursion of forms from outside.

(*b*) *The evidence of 1935.*—During the first part of the year, locusts were practically absent from the summer rainfall areas of Lasbela and Rajputana and were concentrated in the winter-rainfall region of Mekran, where considerable breeding and multiplication occurred. On the other hand, during summer and autumn, locusts were to be found in large numbers in Lasbela and Rajputana area, while locusts evidently belonging to a recent brood and possibly hailing from the Indian Desert areas, were found migrating into the western *reks*. These facts indicate that a mutual seasonal exchange of population had occurred between the two areas. The winter and the summer brood areas look as if they were complementary to each other in the scheme of locust economy.

(*c*) *Biometrical evidence.*—Biometrical studies have proved of great value in providing clues for distinguishing between the locust populations prevalent at different parts of the year. They have shown that an original population composed mostly of *solitaria* individuals had been invaded by a large body of migrants exhibiting *transiens* and *gregaria* ratios, in July 1935 at Pasni. By November, this population was found to have gradually disappeared, giving place to forms of a different type, showing mostly *solitaria* ratios and evidently a newly developed brood. Such a replacement of forms at a time when local breeding had not occurred can only be explained by the phenomenon of migration.

2. Direct evidence

(*a*) *Powers of high flying.*—Direct observations have shown that individuals of the *solitary* type are capable of flying high into the air and vanishing from sight. Long distances may, doubtless, be covered in this way by them when backed by favourable winds.

(*b*) *Experiments with marked individuals.*—In the course of experiments with the liberation of marked locusts, it was in one case noted that a marked *solitaria* individual liberated at Pasni early in May 1935 was recovered at Rumra about 20 miles to the north-east on the 17th of May. This is fairly direct proof in regard to the migratory capacity of the *solitary* locusts.

THE OCCURRENCE OF INCIPIENT SWARMING IN MEKRAN

The character of winter rainfall in 1934-35 and of locust breeding

During the year 1934, the winter rainfall proved a failure in most parts of the Mekran Coast, and the only area where good rainfall was recorded was the Jask region in Iranian Mekran where nearly five inches of rain was received in March 1934.

There was no locust breeding noticed anywhere in 1934 within the limits of British Mekran, though doubtless some breeding had occurred in the Jask sector of the Mekran Coast.

The winter rains of 1934-35, on the contrary, proved to be both early and copious all over the winter rain areas of Arabia, Iran and Baluchistan. Rains began in November 1934 in the Bushire and Bahrein areas, and in December 1934 good rainfall was recorded in all the areas, about 1·62 in. at Pasni and 5·25 in. at Gwadar. There were good falls in January in all the Mekran stations. Rainfall continued till the middle of February, after which there was little precipitation along the coast, except at Ormara. Further rainfall occurred, on the contrary, in the interior of Mekran in April, as at Turbat and Panjgur.

With the advent of the winter rains, fair numbers of locusts were found on the coastal *reks* and oviposition probably began early in January 1935. Green hoppers were found in good numbers on all the coastal *reks* during March, April and May. The first adults of the new generation were noted in the first week of April on all the coastal areas. Hoppers were noted also in the interior—in Kulanch and Kolwa during April. By May moisture had disappeared in the *rek* soils along the coast but in the interior valleys of Mekran, wherever further rainfall had been received in April-May, places suitable for oviposition were present, especially along the beds of streams and the banks of the bigger rivers. In Kulanch, fair numbers of hoppers were thus being found during June on bushes of *Chrozophora* sp. along the beds of some of the streams. Possibly, the hoppers of June represented the second generation of the locust.

While the general coloration of the hoppers was found to be green on most of the *rek* areas, a small percentage of brownish green hoppers with darker patches on the thorax and abdomen was also being noted on the Pasni and Ormara *reks* and in Kulanch. Possibly, these may be taken to represent forms of the *transiens* type.

Three reports of gregarious hoppers in Mekran and Kharan

In June and July, reports of the occurrence of *gregarious* hoppers attacking cultivated crops were received from the Kalat State authorities. As they were received very late, a proper investigation of the outbreaks could not be made. The following information was collected by the Fieldman who visited the Mekran areas subsequently.

1. Shashtal area in Kech Valley.—The Turbat Fieldman was informed about June 14th by the Naib of Turbat that a report had been received to the effect that crops at Shashtal near Nodez had been attacked by bands of hoppers. Under instructions from Pasni, he visited the area on the 17th. He was informed by the owner of the field that " about forty days previously bands of black hoppers, hatched on the adjoining sandy *reks*, had entered his field of *jowari* (sorghum) and pulses, and had damaged them. The hoppers had later on turned yellow in colour, and had ultimately disappeared after acquiring wings about ten days ago ". It was reported that various predaceous birds as well as jackals had been attacking the hoppers. The Fieldman reported that he had noted at the time of his visit about 400 adults within an area of 800 sq. yds., as also a number of hoppers of yellow colour on the crops. He also noted the presence of several green hoppers on wild bushes as also of grey coloured adults in the neighbourhood. Locust Research Assistant, Mr. R. N. Batra, visited this area about the 6th July, and could then find only about thirty-three adult locusts in that field.

2. Sehgazan and Gar areas near Panjgur.—On the 22nd July, a report was received from the Naib-Wazir-i-Azam, Mekran, from camp Pasni, to the effect that the Janishin of Panjgur had noticed an infestation by locusts in *jowari* cultivation at Sehgazan on the 7th July and at Gar on the 8th. The area was examined by the Turbat Fieldman on the 12th August, when very few locusts were to be seen. According to his report " the cultivators had encountered about two months ago, a ' flood ' of hoppers of black colour entering the crops at Sehgazan and Gar from the banks of the Rakshan and the Gwargo respectively, and damaging them ". At the time of the visit of the Janishin both hoppers and locusts were noted. All the hoppers had since turned into adults, which disappeared about the middle of July, when the " Gorich " or the dry wind from the north began to blow over the area.

3. Washuk area in Kharan.—The Nawab of Kharan reported to the Political Agent, Kalat about the occurrence of locust hoppers at Balgattar and at Macho in the sandy desert near Washuk at the beginning of July. Information

was later on obtained from the Nawab to the effect that the hoppers had been killed by the intense heat of the desert sands, though perhaps they had in reality become dispersed among the scattered vegetation and been lost sight of.

The significance of these reports

During years of infestation, reports of the occurrence of *gregarious* hoppers would carry no special significance. During the first half of 1935, however, no swarms were reported anywhere, and in the case of the infestations reported from Mekran it was specially stated that no locust swarms had been noted. The appearance of hoppers in large numbers and the assumption of black and yellow coloration by them are rather extraordinary phenomena, not noted since 1932 anywhere in Mekran, and the question as to how these infestations originated is, therefore, of special interest.

In the Shashtal infestation, it is probable that eggs had been laid about the middle of April, while in the Sehgazan and Gar ones, and possibly also in the Washuk case, oviposition had occurred early in May 1935. During the periodical surveys carried out in the Panjgur-Kech-Kolwah areas, locusts were not met with during the months of January, February and March 1935, but were encountered in fairly good numbers in April and May. This circumstance rather suggests that a migration of the solitaries of the coastal areas—made up in part of adults of the new generation and, perhaps, in part of the old generation as well,—had occurred during April, for by that time, the surface moisture of the coastal *reks* had dried up to a great extent making further breeding an impossibility, and the strong south-west wind, which had set in by that time, had possibly helped to carry the migrants into the hinterland.

In the interior of Mekran, which is to a large extent either hilly or stony, places suitable for oviposition are of limited occurrence, being restricted to silt accumulations on the banks of the rivers, mounds of blown silt at the base of hills or the sandy beds of hill streams, and it is possible, therefore, that a concentration of the solitary phase migrants had occurred on these spots at the time of egg-laying, and had led to mass-oviposition on a small scale. The continuance of rainfall in the hinterland in April is a circumstance that must have favoured egg-laying. After hatching, the hoppers had presumably undergone a compulsory crowding in the patches of *jowari* cultivation found in the close neighbourhood, and it is not unlikely that the patches of *jowari* had themselves functioned as the original points of attraction for the *solitary* locusts. In one case, enquiries actually showed that part of the egg-laying had occurred in the field itself.

In all cases, the resultant adults are reported to have disappeared after acquiring wings. As the Fieldman could not examine these infestations early enough, it is not possible to make any statements on the phase characteristics of the new adults, but specimens found by him after the main body had flown away, showed mostly ratios of the *solitaria* type.

These cases are of special importance from the point of view of Locust research. They had occurred not only at a time when there were no swarms about, but also at a juncture just prior to the wide-spread locust incursion noticed in many parts of North-West India in July. If the assumption made as to the origin of these infestations from migrant parents of the *solitary* phase type could be confirmed, these cases would have to be considered to have been actual instances of the transformation of phase *solitaria* into phase *gregaria*, or in other words, the localities where this had occurred should be regarded as some of the actual *outbreak centres*.

Records of outbreak centres in the past

In this connection, it may be recalled [Rao, 1933], that in the year 1923 a locust infestation of a fairly serious character had been recorded at Zahrenbug and Hasadi in cultivated areas in the rich, silt-laden valley of the Dasht River. Hoppers first appeared early in May, and millions of them were being found in a wide area extending from Zahrenbug upto Gabd towards the south. The adults emerging from the hoppers are ultimately said to have disappeared into the jungles by the end of June. It is notable that the infestation had occurred, as in the case of Shashtal, in May-June. There is little doubt that it had originated from migrants derived from the coastal population, which had presumably gone through one generation already by reason of the early rainfall of January 1923. The Kachhi records show that in July-August of the same year, locusts were found damaging *jowari* crops at Dhadhar.

In 1926 also, locusts and locust hoppers were reported to be damaging cotton and *jowari* (*sohru*) crops in the Kulanch area, during the month of June 1926. Locusts were also said to have been present near Tump in June. As there had been very heavy rainfall along the coast and interior of Mekran in January 1926, heavy locust breeding had evidently occurred on the coastal *reks*, and the breeding reported in the silt soils of Kulanch, induced obviously by the good rainfall recorded in the hinterland of Mekran in March and May, presumably represented the second generation of the year. Locusts are reported to have disappeared from Kulanch by the latter half of June, and records show that fliers were in evidence by the end of June in Mirpur-Nasirabad Niabat near Gandhawa in Kachhi and at Kurk near Sibi in the first week of July.

There is little doubt, therefore, that the infestation recorded in 1923 in Dasht Niabat, and in 1926 in Kulanch were of the same character as the Shashtal, Sehgazan and Gar outbreaks, and that they should all be classified as incipient outbreaks produced in the chain of circumstances following early and plentiful winter rainfall in the Mekran areas.

The probable origin of the July incursion

The instances of incipient swarming reported this year from Mekran show that wherever conditions are favourable for development, a second generation

of the locust would be produced. As Mekran is a vast area with a very sparse population, it is not unlikely that besides the cases reported, similar other outbreak centres had come into existence during the year, but had remained unreported as the damage was not considered serious enough. Similarly, it should not be considered surprising if such swarming had also developed unnoticed in uncultivated areas supporting sufficient vegetation. In any case, there is little doubt that there were large numbers of locusts present in various parts of Mekran during June and July. Since in the adjoining province of Iranian Baluchistan, conditions were presumably identical, it is not improbable that similar outbreak centres had come into existence at about the same period, and if so, a considerable multiplication of the locust population must have taken place in that area also.

From May onwards, the climatic conditions of the hinterland of Mekran usually undergo a gradual change from the temperate character of spring to the extremely torrid conditions of summer, characterised by high temperatures and low humidity and the prevalence of dry hot winds from the north or north-west, so that by June or July a zone of dry and hot climatic conditions develops in an extensive area inclusive of large parts of Persia and Afghanistan, which locusts are obviously unable to stand and try to flee from. The local wind directions would carry them either southwards to the coastal areas or eastwards into the plains of India. When locusts enter the monsoon zone, the prevalent south-west wind would carry them into the areas of Kachhi, Sind and Rajputana. Lean's observations [Lean, 1931] in Nigeria show that the swarms of *Locusta migratoria migratorioides* prefer a zone of relative atmospheric humidity between the limits of eighty and forty per cent. and try to avoid regions above or below those limits. *Schistocerca* apparently exhibits a similar dislike for very dry as well as very humid atmospheric conditions. Ballard and Mistikawy have shown [Ballard and others, 1932] that seasonal winds have a great influence on the directional trends of swarms of the Desert Locust. What applies to swarms may also apply equally to individual flights.

In view of the facts detailed above, there appears to be little doubt that the locust incursion of July 1935 had had its origin in part at least in the Mekran area, to which the centres of swarming noted at Shashtal, Sehgazan, Gar and Washuk had apparently contributed their quota, though, on account of the extraordinarily high numbers characterising the incursion, it is probable that the bulk of it must have had an extra-Indian origin.

Breeding in the summer-brood areas

Although fairly large concentrations of locusts had been noted in July in quite a large number of places in Sind and Rajputana, breeding was greatly restricted on account of the lack of well-distributed rainfall. There was no rainfall, and consequently no breeding whatever, in Lasbela and Karachi areas and in

Mekran. Good rainfall occurred only in the Bikaner area, in South Marwar and Thar-Parkar, and even in these regions there were only light falls in August and September.

Comparative rainfall figures in 1935 and 1926 in inches

Places	1935			1926		
	July	August	Sept.	July	August	Sept.
Barmer . .	4·34	0·80	1·50	3·51	4·17	8·35
Chachro . .	8·18	2·47	0·49	2·25	7·91	5·52

A fair amount of breeding was noted in Thar-Parkar, Mallani and parts of Bikaner during July-August, but on account of the insufficiency of rainfall, breeding was neither dense nor extensive. On the other hand, owing to the heavier and continued monsoon in 1926, the breeding was so heavy as to start a new cycle of locust infestation.

The first adults of the new generation were noted at the end of August 1935. Some hoppers were still being found in October and November in Thar-Parkar District, which probably represented the second generation of the monsoon. After October the locust population in the Rajputana desert began to show a gradual decrease in numbers, till by the end of November very few could be seen except in the Thar-Parkar area. Since about the same time, the arrival of solitary specimens of the new generation was detected in October-November in the Lasbela area, and at Pasni in November, a migration from east to west had obviously occurred.

A cursory study of the meteorological data has shown that, with the withdrawal of the monsoon in September, a zone of low humidity develops in the Rajputana area, which apparently causes the locusts to migrate out of the area. At the same time a change in the direction of the prevailing wind from south-west to north-east, taking place about the middle of October, presumably plays a great part in bringing about the westward migration of the locusts from the desert area.

Conclusions

In reviewing the various observations made in 1935 in connection with the locust developments of the year, it may be stated that they have led to a considerable advance in our knowledge of the life-habits of the Desert Locust. Some deductions that may perhaps be made in regard to the mode of origin of the infestation in the Indian area are briefly outlined below, and a few notes have also been added in connection with the aspect of control in the breeding grounds.

1. It appears probable that early and copious winter rainfall would lead to extensive breeding on the coastal *rek* areas and bring about a great increase in the general population. The new generation of adults would appear by April and migrate into the interior in the absence of conditions favourable for further breeding on the *reks*. Should there be rainfall at this juncture in the interior of Mekran, concentrated egg-laying would occur in suitable areas, leading to incipient swarming.

2. The adults of the second generation would migrate into Sind and Rajputana by individual flights, or perhaps as small loose swarms, and if the monsoon rainfall should be favourable, as in 1926, further multiplication would occur and lead perhaps to the formation of large swarms. Otherwise the locust invasion would fizzle out.

3. The flights that are responsible for the starting of a new cycle of infestation in India would appear always to come from the direction of Mekran, but this is not generally recognised, as the arrival of locusts may take the form of a migration of individual locusts as during 1935, and is then not easily noticed. This had presumably happened in 1926, and probably also in 1923. In both these years, the entrance of locusts in June-July into India is indicated by records of actual occurrence of locusts at this period in parts of the Kachhi area in July 1926 and in July-August 1923 on cultivated crops. In studying the origin of locust cycles of the past, prior to 1926, in India, due consideration should be given to this circumstance owing to the general incompleteness of the records.

4. The evidence found in regard to the capability of the solitary locust for migration indicates that it is eminently adapted to escape the effects of local drought. If winter rains should fail in one area, it could always migrate to another better favoured area, and, in the last resort, may be able to reach regions of summer rainfall. Usually there appears to be a mutual exchange of population between the western *reks* and the desert areas, and since they function equally well as regions of habitat of the locust, they should be considered to be complementary to each other.

5. In devising measures to check the swarming of the locust, it would appear futile to attempt to deal with the general breeding in the areas of habitat, as on account of the extent of the area and the scattered nature of distribution of the *solitary* locusts control measures would be uneconomical. On the other hand, it would be comparatively easy to deal with the concentrations of hoppers appearing at the time of incipient swarming. Special attention will, therefore, have to be paid to the location of such outbreak centres and prompt steps will have to be taken to deal with the incipient swarms. Since outbreak centres of the Indo-Iranian region are likely to develop in Iranian Mekran also, international co-operation would be essential, to ensure efficiency of control.

Acknowledgments

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Explanations of Figure and Maps.

Fig. 1.—Graph showing the fluctuation in the locust population in the Pasni and Ambagh *Reks* during a period of four years, 1932 to 1935.

Maps.—Map I : showing the distribution of the Locust in the breeding grounds in the Indian area between December 1934 and June 1935.

Map II : showing the distribution between July and November 1935.

APPENDIX I

Results of a biometrical analysis, month by month, of a series of locust specimens collected mainly from the Pasni reks *during 1935*

N.B.—For purposes of convenience, the following E/F ratios will be considered to signify the different phases :
2·05 and below : *Solitaria*.
2·06 to 2·15 : *Transiens* or *Intermediate*.
2·16 and above : *Gregaria*.

Month	Place of collection	Total number of specimens examined	Phase of the specimens	Total number of each phase	E/F ratios	Remarks
January, 1935	Pasni	12	Sol.	11	1·97, 1·99, 2·00, 2·00, 2·01, 2·02, 2·03, 2·03, 2·04, 2·04, 2·04.	Mostly *solitaria* and with traces of purple in hind wings.
			Int.	1	2·15.	
February, 1935	Pasni	10	Sol.	9	1·98, 2·00, 2·00, 2·02, 2·04, 2·04, 2·05, 2·05, 2·05.	Veins with traces of purple in hind wings, which are mostly yellow.
			Int.	1	2·07.	
March, 1935	Pasni	7	Sol.	5	1·93, 1·95, 2·03, 2·03, 2·05	Hind wings yellow.
			Int.	2	2·06, 2·13.	
April, 1935	Pasni	4	Sol.	3	2·04, 2·05, 2·05	Some with hyaline wings.
	Kalmat		Int.	1	2·09 (Hyaline wings).	
May, 1935	Pasni	8	Sol.	6	1·93, 2·00, 2·03, 2·03, 2·03, 2·05	Some with hyaline wings, others with bright yellow ones.
	Ormara		Int.	2	2·07, 2·08.	
	Kulanch					
June, 1935	Non-available.					
July, 1935	Pasni	19	Sol.	12	1·94, 1·95, 1·98, 2·00, 2·01, 2·03, 2·04, 2·04, 2·04, 2·04, 2·04, 2·05.	Collected mostly between the 12th and 15th July.
			Int.	4	2·09, 2·12, 2·13, 2·15.	An incursion of locusts on a large scale took place about the 12th July and the migrants were largely *transiens* and *gregaria*.
			Greg.	3	2·16, 2·18, 2·24.	
	Ormara	1	Greg.	1	2·29.	
August, 1935	Pasni	21	Sol.	5	1·94, 2·01, 2·01, 2·03, 2·03.	Population composed largely of migrants.
			Int.	10	2·06, 2·07, 2·07, 2·09, 2·10, 2·13, 2·13, 2·13, 2·15, 2·15.	
			Greg.	6	2·16, 2·19, 2·19, 2·21, 2·22, 2·23.	
	Ormara area	60	Sol.	9	1·90, 1·96, 1·98, 2·00, 2·02, 2·02, 2·03, 2·05.	Many of the specimens were either pinkish or had a pinkish tinge in the hind wings ; some were bright yellow, especially the males. Others had fairly conspicuous stripe
			Int.	38	2·06, 2·06, 2·07, 2·07, 2·07, 2·08, 2·08, 2·09, 2·09, 2·09, 2·09, 2·09, 2·10, 2·11, 2·11, 2·11, 2·11, 2·11, 2·12, 2·12, 2·12, 2·13, 2·13, 2·13, 2·13, 2·13, 2·14, 2·14, 2·14, 2·14, 2·14, 2·14, 2·15, 2·15, 2·15, 2·15, 2·15.	
			Greg.	13	2·17, 2·19, 2·19, 2·20, 2·21, 2·22, 2·22, 2·22, 2·23, 2·25, 2·25, 2·29, 2·34.	

APPENDIX I—*contd.*

Month	Place of collection	Total number of specimens examined	Phase of the specimens	Total number of each phase	E/F ratios	Remarks
September, 1935	Pasni 31 Ormara 2	33	Sol.	8	1·95, 1·96, 2·00, 2·00, 2·01, 2·04, 2·05, 2·00.	Mostly composed of July migrants, but the general population had decreased; almost all of the specimens met with showed conspicuous stripes of the *Solitaria* type, though the ratios varied a great deal. Most had yellowish wings.
			Int.	16	2·06, 2·07, 2·07, 2·07, 2·09, 2·09, 2·09, 2·10, 2·10, 2·10, 2·11, 2·13, 2·14, 2·14, 2·15, 2·12.	
			Greg.	9	2·16, 2·18, 2·19, 2·20, 2·21, 2·21, 2·22, 2·24, 2·26.	
October, 1935—						
12-17/-X-35	Pasni	15	Sol.	4	2·00, 2·01, 20·2, 2·05	Population had greatly diminished, specimens rather dark and conspicuously striped. Hind wings showed traces of mauve and light blue. Mostly remnants of the July migrants.
			Int.	5	2·06, 2·07, 2·13, 2·14, 2·15.	
			Greg.	6	2·16, 2·16, 2·17, 2·17, 2·19, 2·23.	
28-30/-X-35	Pasni	21	Sol.	8	1·94, 1·94, 1·96, 1·96, 1·96, 1·97, 2·03, 2·04.	
			Int.	6	2·06, 2·08, 2·09, 2·10, 2·11, 2·15.	
			Greg.	7	2·16, 2·16, 2·16, 2·17, 2·17, 2·18, 2·21.	
November, 1935— 1st fortnight	Pasni	24	Sol.	14	1·94, 1·95, 1·96, 1·97, 1·97, 1·98, 1·98, 1·99, 2·01, 2·01, 2·03, 2·03, 2·04, 2·04.	The proportion of *Solitaria* greatly increased during the month, and as most of them had bluish or purplish hyaline hind wings, they probably belong to a recent brood. As similar forms have been noted at Ambagh, Hingol, and Ormara since the middle of October, it is considered that they are probably migrants from the Rajputana Desert areas. A few of the old July migrants also found.
			Int.	10	2·06, 2·08, 2·08, 2·11, 2·11, 2·13, 2·13, 2·14, 2·15, 2·15.	
2nd fortnight	Pasni	27	Sol.	20	1·83, 1·92, 1·92, 1·93, 1·93, 1·95, 1·95, 1·96, 1·97, 1·97, 1·98, 1·98, 1·99, 2·00, 2·00, 2·00, 2·00, 2·00, 2·04, 2·05.	
			Int.	5	2·10, 2·11, 2·11, 2·12, 2·14.	
			Greg.	2	2·16, 2·22.	

Appendix II

Results of a biometrical analysis, month by month, of all available locust specimens collected mainly from the Mekran Coastal reks *during 1934*

N. B.—For purposes of convenience, the following E/F ratios will be considered to signify the different phases :
2·05 and below : *Solitaria.*
2·06 to 2·15 : *Transiens* or *Intermediate.*
2·16 and above : *Gregaria.*

Month	Place of collection	Total number of specimens examined.	Phase of the specimens	Total number of each phase	E/F Ratios	Remarks
January February, and March, 1934	Preserved specimens not available.					
April, 1934	Gwadar 1 (G) Pasni 3 (P) Ormara 3 (O) Awaran 1 (A)	8	Sol. Int.	6 2	1·90 (O), 1·92 (A), 1·95 (O), 2·00 (O), 2·00 (P), 2·03 (P). 2·07 (G), 2·13 (P).	Specimens mostly with bright stripes and yellow hind wings.
May, 1934	Pasni 3 Gwadar 1 (G)	4	Sol. Int. Greg.	1 2 1	1·92 2·07, 2·12. 2·20 (G).	2·20 with almost hyaline, and 2·12 with pinkish hind wings. Apparently both were recently fledged ones.
June, 1934	Pasni	2	Sol.	2	1·98, 2·01.	
July, 1934	Pasni 2 (P) Pishukan 1 (Pn) Kappar 1 (K)	4	Sol. Int. Greg.	*Nil* 2 2	..... 2·10 (K), 2·11 (P). 2·20 (Pn), 2·26 (P).	All specimens appear to be locusts of a recently developed brood.
August, 1934	Pasni 1 (P) Gwadar 1 (G)	2	Sol. Int.	1 1	2·03 (G) 2·06 (P).	Locusts scarce in all *reks*.
September, 1934	No specimens preserved.					
October, 1934	Gwadar	2	Sol.	2	2·00, 2·04	2·04 Hind wings purplish; stray specimens found at Gwadar, but none on the Pasni *reks*.
November, 1934	...	...	...	...	.....	No locusts were found anywhere on the Mekran *reks*.
December, 1934	Gwadar 1 (G) Pasni 6	7	Sol. Int.	5 2	1·93, 1·96, 1·96, 2·01, 2·01 (G) 2·06, 2·07.	All specimens showed purplish tinge in the hind wings. They appear also to be a recently developed brood.

SINGLE-VALUE SOIL PROPERTIES : MOISTURE AT THE STICKY POINT AND *R*

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I. Introduction

Working with soils of the same type from a restricted area, Prescott and Poole [1934] have shown that mechanical analysis may be related to certain single values such as Moisture at the Sticky Point, Moisture Equivalent, etc., in a simple fashion. That different replaceable bases may have an influence on single value soil properties has been shown by Baver [1928] and by the writer [Charlton, 1932]. Baver's results were not available to the writer until quoted in a paper by Baver and Horner [1933]. In the case of Lower Burma paddy soils, correlations as high as $r=0\cdot93$ had been found between mechanical analysis expressed as clay and silt and the moisture at the Sticky Point and $r=0\cdot95$ between mechanical analysis and the value R. Such high values were only obtained after hydrogen peroxide treatment and saturation with a single cation, preferably H′ or Ca″. The soils used were those for which single values have already been published [Charlton, 1932]. Although the regression equations connecting moisture at the Sticky Point and R with mechanical analysis enabled the values to be calculated with considerable accuracy, the equations were not applicable to the

calcareous soils of Upper Burma even after treatment with hydrogen peroxide and saturation with the same cation as was used with the Lower Burma paddy soils. The object of the work described in this paper was to discover the reasons underlying this difference in behaviour.

II. The soils used

Thirty-eight soils were used. Of these Hmawbi, B. 610, B. 616, B. 618 and B. 624 are Lower Burma paddy soils. These soils are all fairly highly leached soils on old alluvium. B. 951, B. 957, B. 988, B. 992, B. 999, B. 1010, B. 1015 and B. 1031 are typical tropical or sub-tropical red soils at an elevation of about 2,000 feet under a rainfall sufficient to remove all but small amounts of replaceable bases. These soils are under forest planted to *Gmelina arborea*, a tree requiring good drainage for successful growth. Soils B. 1129, B. 1131, B. 1133 and B. 1135 are sugarcane soils in the Bilin tract, subject to occasional flood and are under an annual rainfall of 200 in. per annum or more. B. 1137, B. 1139, B. 1141 and B. 1143 are sugarcane soils from Shwegun also under a rainfall of at least 200 in. per annum but are not subject to flood. Nanda Tank and Mandalay soils Nos. 1-57 are calcareous Mandalay-Canal area soils which in their natural condition without irrigation approach closely the Solontschak type, while the three Singaing soils differ little from the Mandalay type but being closer to their canal headworks tend to receive more silt in the irrigation water and being rather lighter in texture than the usual Mandalay-Canal area soils grow sugarcane as well as paddy. The thirty-eight soils so chosen were deliberately selected to include wide variations in geological formation, rainfall and texture. It will be noted that although none of the soils is a laterite a few are lateritic according to Martin and Doyne's definition [1927] while the ratio SiO_2/Al_2O_3 (molecular) covers the range 1·62-4·30.

III. Methods employed

(*a*) *Clay Equivalent* (CE).—The method of mechanical analysis used was the revised British Official Method [1928] with the exception that organic matter was removed by Troell's method [1931] using cold NaBrO solution instead of hydrogen peroxide. This method was found preferable to hydrogen peroxide since sesquioxides were not dissolved and further, whereas hydrogen peroxide was found to be practically without effect on the organic matter of calcareous soils, oxidation by cold NaBrO solution proceeded smoothly and as efficiently as in sour or neutral soils. In certain soils containing large amounts of organic matter two treatments were necessary. Russell [1933] has shown that more than eighty per cent of the total variance of the Xylene Equivalent and Moisture Equivalent is accounted for by the clay and fine silt fractions and that the residual variance is not decreased by taking into account the fractions coarser than fine silt. Hence, since in the Atterberg scale the silt fraction is ten times the size of the clay it was considered justifiable on the grounds of simplification

to add one-tenth of the silt fraction to that of the clay and to utilize the value so found as a single term called the " Clay Equivalent ". Certain unjustifiable assumptions are thereby implied but the mathematical treatment is so much simplified that it was considered justifiable to make use of the conception.

(*b*) *Base Exchange Capacity* (BEC).—The method of F. W. Parker [1929] using his barium acetate-ammonium chloride procedure was employed.

(*c*) *Moisture retained by soil in 50 per cent saturated atmosphere* (R).—Thin films of soil, each of approximately equal weight were exposed in identical squat form weighing bottles to sulphuric acid of appropriate strength at 30°C.

(*d*) *Moisture at the Sticky Point* (S).—The method of Keen and Coutts [1928] was followed with the modification that all soils were first of all made rather too moist and were then worked in the fingers until sufficient moisture had been lost to reduce the soils to the desired condition.

(*e*) *Preparation of calcium soils.*—Two series of calcium soils were prepared. In one series the organic matter was removed by treatment with cold NaBrO solution while in the other this treatment was omitted. After treatment with NaBrO in the first series, excess of bromine was removed by dilute ammonia and then the soils were treated twelve times by decantation with *M* calcium chloride solution, transferred to filter papers, washed twelve times with *M*/10 calcuim chloride solution and were finally washed with freshly boiled distilled water until the filtrates were free from calcium and chlorine ions. In the second series the treatment was identical except that the NaBrO treatment was omitted, the soils being directly treated with *M* calcium chloride solution.

(*f*) *Silica-sesquioxide ratio* (*molecular*).—The clay fractions of the soils were separated after removal of organic matter by cold NaBrO and silica and sesquioxides in the clay were then determined after fusion of the clay with excess sodium carbonate.

Carbon dioxide, loss on ignition, etc. were determined in the usual way. In the case of the untreated (original) soils, no treatment with ammonium carbonate was given in determining loss on ignition as such treatment is likely to affect the results to some extent. With calcium chloride and NaBrO treated calcium soils, after ignition the soils were ' moistened ' with ammonium carbonate solution and dried to constant weight at 105°C. Organic carbon was determined by wet combustion and the values so obtained were multiplied by the conventional factor 1·818 to give the organic matter. The difference between loss on ignition and organic matter was assumed to be the combined water (*CW*).

It has been assumed in this paper that a single set of values for *CE*, *BEC* and $\frac{SiO_2}{R_2O_3}$ is applicable to all soils whether untreated, treated with *M* calcium chloride only or with NaBrO solution followed by *M* calcium chloride solution. In the case of *CE* the point is not capable of direct proof since in mechanical analysis the

clay is usually determined as ammonium or sodium clay and not as calcium clay. The fact that the *BEC* did not alter significantly as a result of either calcium chloride or NaBrO followed by calcium chloride treatment was proved by actual test on twelve of the soils. In the case of $\frac{SiO_2}{R_2O_3}$ the fact that no loss of silica and sesquioxides could be detected as a result of NaBrO treatment was taken to justify the procedure.

IV. Experimental results

The data obtained for original, calcium and NaBrO treated calcium soils are detailed in Appendix Tables I-III. The total and fifth order partial correlations are given in Appendix Tables IV-VI, all partial correlations except the fifth order being omitted in order to economise space. The level of significance ($P = 0{\cdot}05$) is about $r = 0{\cdot}35$ for a fifth order and $r = 0{\cdot}325$ for a total correlation. In a few cases partial correlations of a lower value than $r = 0{\cdot}35$ have been provisionally used in formulating the regression equations between *SP* and *R* in terms of the parameters *CE*, organic carbon, *CW*, etc.

(*a*) *Effects of treatments on mean values of carbon dioxide, organic carbon, etc.*

The effects of the various treatments employed may first be considered. Results are shown in Table I.

Table I

Effect of treatments on mean values

	CO_2 as carbonate	Organic carbon	Combined water	*SP* moisture	*R*
Untreated soils . . .	1·604	1·398	5·074	40·85	3·361
Calcium soils . . .	1·770	1·489	4·013	41·70	3·393
NaBrO treated calcium soils	1·944	0·828	3·737	40·10	3·104

In considering these results it should be remembered that certain of the determinations are calculated on air-dry soil and as the amount of moisture in air-dry soil may vary as a result of treatments employed, small differences may not be significant. Also certain parameters are expressed on oven-dry soil. There can be no doubt, however, that NaBrO solution removes about forty per cent of the organic matter on the average but the various treatments do not have a very pronounced action on mean values of *SP* and *R*. The most noteworthy effect of the treatments is on *CW*, a reduction of about twenty per cent being effected by simple treatment with calcium chloride solution. Further, this reduction in *CW* is a mean result for all soils, half of which are calcareous. If the Mandalay and Sagaing soils are excluded the reduction of *CW* as a result of calcium chloride treatment (without NaBrO) is 34·7 per cent. This reduction in *CW* (and hence

of *L 1*) as a result of replacement of H′ by Ca′ is the most important fact upon which the equations for *SP* and *R* are derived. If the difference between mean results for calcium and NaBrO treated calcium soils may be attributed solely to removal of humified organic matter it appears that unit weight of such organic matter may take up 2·42 times its own weight of water as *SP* and 0·443 times its own weight as *R*.

(*b*) SP *values*

The fifth order partial correlations detailed in appendix Tables IV-A, IV-B and IV-C show that *SP* is controlled primarily by *CW* and to a less extent by organic carbon and $\frac{SiO_2}{R_2O_3}$ the partial correlations between *SP* and organic carbon and $\frac{SiO_2}{R_2O_3}$ being slightly less than significant in certain cases. As would be expected, the untreated soils show quite different relationships from the calcium and NaBrO treated calcium soils and not much importance can be attached to the values for untreated soils. It was expected that the values obtained for calcium and NaBrO treated calcium soils would check each other fairly closely except as regards the behaviour of organic matter which is of quite different nature in the two cases and of course thereby affects the values for *OW*. Actually the fifth order partial correlations in the cases of calcium and NaBrO treated calcium soils check sufficiently well to support the conclusion that in such soils (saturated with one cation only) *SP* is controlled primarily by *CW* and secondarily by organic carbon and $\frac{SiO_2}{R_2O_3}$. The substitution of the single value loss on ignition (*L 1*) for the two values *CW* and organic carbon in the same soil causes no noticeable reduction in the value of the multiple correlation coefficient and so allows of further simplification. The actual regression equations are given in Table II.

TABLE II

Equations for SP

	Multiple correlation coefficient
A (1) *Original soils*	
$SP = 0{\cdot}1294\,CE + 4{\cdot}929$ org. C $+ 1{\cdot}591\,CW - 0{\cdot}3143\,BEC + 2{\cdot}245\frac{SiO_2}{R_2O_3} + 19{\cdot}98$	0·8490
A (2) *Calcium soils*	
(a) $SP = 4{\cdot}456$ org. C $+ 2{\cdot}786\,CW + 3{\cdot}206\frac{SiO_2}{R_2O_3} + 16{\cdot}78$	0·8826
or	
(b) $SP = 2{\cdot}637\,L1 + 3{\cdot}221\frac{SiO_2}{R_2O_3} + 16{\cdot}76$ . . .	0·8838
A (3) *NaBrO treated calcium soils*	
(a) $SP = 5{\cdot}718$ org. C $+ 4{\cdot}040\,CW + 5{\cdot}800\frac{SiO_2}{R_2O_3} + 7{\cdot}28$.	0·9028
or	
(b) $SP = 3{\cdot}708\,L\,1 + 6{\cdot}267\frac{SiO_2}{R_2O_3} + 6{\cdot}62$	0·9015

The increase in value of the multiple correlation coefficient as a result of the treatments given is not significant but this may be attributed to the greater number of constants fitted in the case of the untreated soils. Apart from the fact that substitution of *L 1* for *CW* and organic carbon causes practically no change in the multiple correlation coefficient, the calculated values for *SP* detailed in Appendix Table VII-A are practically identical. It may be noted that in the case of the calcium soils, the constant approaches closely to 16, *i.e.*, the usual limiting value for very sandy soils in closest packing. In the case of NaBrO treated calcium soils the constant has a much smaller value and hence it appears likely that NaBrO has a pronounced effect on the packing of the soil particles.

(*c*) R *values*

The fifth order partial correlations detailed in appendix Tables IV-B and IV-C do not check so well as in the corresponding partial correlations for *SP*. As in the case of *SP* however, *CW* is the most important parameter while *BEC* gives a significant correlation in all cases. *CE* is on the verge of significance for NaBrO treated soils only. Carbon dioxide is significant in the case of original and calcium soils only while $\frac{SiO_2}{R_2O_3}$ is significant in the case of original and calcium soils only. The omission of $\frac{SiO_2}{R_2O_3}$ in the case of NaBrO treated calcium soils causes the calculated values given in Appendix Table VII-B to fall in to classes determined by soil type, in spite of the comparatively low partial correlation coefficient ($r = 0{\cdot}1949$) between R and $\frac{SiO_2}{R_2O_3}$. In the case of NaBrO treated calcium soils, two equations have therefore been given, one with and one without taking into consideration $\frac{SiO_2}{R_2O_3}$.

The equations for R are given in Table III.

TABLE III

Equations for R

	Multiple correlation coefficient R
B (1) *Original soils.*	
$R = 0{\cdot}1819\,CO_2 + 0{\cdot}2139\,CW + 0{\cdot}1437\,BEC + 1{\cdot}325\frac{SiO_2}{R_2O_3} - 3{\cdot}129$	0·9166
B (2) *Calcium soils*	
$R = 0{\cdot}1053\,CO_2 + 0{\cdot}3828\,CW + 0{\cdot}1428\,BEC + 1{\cdot}002\frac{SiO_2}{R_2O_3} - 2{\cdot}708$	0·9572
B (3) *NaBrO treated calcium soils*	
(a) $R = 0{\cdot}03121\,CE + 0{\cdot}4030\,CW + 0{\cdot}06065\,BEC - 0{\cdot}653$	0·9126
or	
(b) $R = 0{\cdot}01111\,CE + 0{\cdot}4918\,CW + 0{\cdot}0870\,BEC + 0{\cdot}7828\frac{SiO_2}{R_2O_3} - 2{\cdot}266$	0·9371

The improved values of the multiple correlation coefficient as a result of soil treatments are not significantly better than that for the untreated soil. Even when $\frac{SiO_2}{R_2O_3}$ is included in equation B (3) (b) the soils still tend to fall into classes according to their origin but the agreement between observed and calculated values is better for equation 3 (B) (b) than for 3 (B) (a). The constant becomes relatively large when $\frac{SiO_2}{R_2O_3}$ appears because the minimum value of $\frac{SiO_2}{R_2O_3}$ for any soil is 1·42 and the average 2·24. It appears that NaBrO treatment has proved unexpectedly drastic in its effect on *R*. The partial correlations for carbon dioxide, *CW*, *BEC*, $\frac{SiO_2}{R_2O_3}$ and *R* check very well in the case of original and calcium soils but of these values only *CW* and *BEC* retain significance in the case of NaBrO treated soils. These differences must be ascribed to NaBrO treatment.

V. Discussion of results

Martin [1928] has pointed out that tropical soils have higher *CW* than non-tropical soils, pointing out that H and F. J. Warth obtained up to 28·1 per cent *CW* for Indian laterites while Lacrois found up to 30 per cent in French Guinea and Koert up to 27·9 per cent at Amani, Tanganyika. Martin also pointed out that *CW* is inversely proportional to the $\frac{SiO_2}{Al_2O_3}$ ratio in the clay if ferric oxide is constant. Coutts [1929] from his studies on Natal soils gave the following equation connecting *SP* and *L 1* :—

$$SP = 2{\cdot}05\ L\,1 + 17{\cdot}6 \pm 3{\cdot}1$$

and the relatively poor fit of this equation may possibly be due to the fact that the soils were of varying degrees of saturation. The fact that *CW* or *L 1* is reduced by replacement of H ions by Ca"agrees with Jenny's contention [1932] that part of the combined water in H systems is the " potential water molecules " formed by exchangeable H ions and the OH ions in the alumino-silicate crystal lattice framework. The partial correlation coefficients detailed in Tables IV--VI leave no room for doubt that both *SP* and *R* are directly related to *CW* and that, other things being equal, not only will *SP* and *R* tend to be greater with tropical than with non-tropical soils but in general both *SP* and *R* will be higher in sour than in neutral or calcareous soils.

The multiple correlation coefficients for the equations given in Tables II and III are all very significant but the application of the equations to the calculation of *SP* and *R* shows that while *SP* may be calculated satisfactorily, the calculated values of *R* in many cases differ so widely from the actual values that the equations for *R* are of little or no practical use. This is clearly shown in Appendix Table VIII. The fact that *SP* may be fairly accurately calculated in soils containing only one replaceable base whereas *R* cannot be satisfactorily calculated, in spite

of the higher multiple correlation coefficients, is to be ascribed to the fact that *SP* includes about sixteen per cent interstitial water which is included within the *SP* values, so rendering errors between actual and calculated values of a lower order than is the case for *R* which includes no such interstitial water.

For practical use the calcium soils offer advantages over the NaBrO treated calcium soils. Reference to Appendix Table VII-A shows that equations A (2) (a) and A (2) (b) give almost identical results, the maximum difference in the calculated *SP* values for any soil being only 0·50. Both equations break down in one case only, *e.g.* for soil B. 624 which is a very sandy soil in which the determination of *SP* is difficult and almost meaningless. Since equations A (2) (a) and A (2) (b) give practically identical results there is no real advantage in expressing *L 1* separately as organic carbon and *CW*. In equation A (2) (b) the partial correlation between $\frac{SiO_2}{R_2O_3}$ and *SP* is of a low order only, *viz.* $r = 0{\cdot}2924$ with *P* about 0·1. Hence the equation may not be used for calculating $\frac{SiO_2}{R_2O_3}$. Also, if $\frac{SiO_2}{R_2O_3}$ be omitted, the equation further simplifies to

$$SP = 2{\cdot}637\ L\,1 + 23{\cdot}98$$

the correlation between *SP* and *L 1* having the highly significant value of 0·8672. Hence in soils saturated with calcium and containing no extreme ratios of $\frac{SiO_2}{R_2O_3}$, provided such soils are not extremely sandy, this equation fits very well. When applied to the corresponding soils in this case, twenty-seven soils have an error less than ten per cent, nine between ten and twenty per cent and two have an error greater than twenty per cent. The last two cases occur with soils B. 624 and B. 951. The sandy nature of B. 624 has already been referred to while B. 951 has more non-humified organic matter than any of the soils used although whether this is the cause of the difference between actual and calculated *SP* values is not known.

On the whole, therefore, the information yielded by determination of *SP* appears to offer no advantages over that given by *L 1* and since *L 1* is a much better controlled determination, less subject to personal errors, *L 1* is to be preferred to *SP*.

The case of *R* is by no means conclusive. So far as information yielded by the parameters used is concerned, *SP* and *R* seem to differ fundamentally although both are influenced largely by *CW* in the same direction. Thus organic carbon seems to be without effect on *R* but influences *SP* while carbon dioxide and *BEC* affect *R* but not *SP*. Of the parameters which affect *R*, *CE*, *CW* and $\frac{SiO_2}{R_2O_3}$ are in turn known to be correlated to *BEC* and hence it appears that *R* is much more influenced by *BEC* than *SP*. The fact that *BEC* alone is not adequate to determine *R* is possibly due to imperfections in the method used to determine *BEC*.

Also the substitution of $\frac{SiO_2}{Al_2O_3}$ (molr.) for $\frac{SiO_2}{R_2O_3}$ (molr.) might possibly simplify the relationships but there is at present no possibility of re-examining the work on these lines. Perhaps the most surprising part of the work is the fact that organic carbon is without influence on *R*. This emerges from treated and untreated soils, all three cases showing a negligible partial correlation between *R* and organic carbon. Although *R* appears to depend upon *BEC* and parameters related to *BEC* and also to the amount of carbonates present in the soil, the relationships obviously require further examination. Certain of the determinations, especially organic carbon and *CW* are approximate only and as a result the dependence of *R* upon *CE*, *CW*, carbon dioxide, etc. may be obscured. The small errors due to use of parameters based on air-dry soil and in other cases on oven-dry soil may also possibly contribute to the same result.

VI. Conclusions and summary

1. In an examination of the effect of clay, carbonates, organic carbon, combined water, $\frac{SiO_2}{R_2O_3}$ (molecular) in clay and base-exchange capacity on moisture at the Sticky Point and *R*, in untreated soils and in the same soils saturated with calcium, with and without removal of humified organic matter, considerable differences in behaviour of *SP* and *R* have been found.

2. Cold NaBrO solution removed about forty per cent organic matter on the average and was as successful with calcareous as with sour soils whereas hydrogen peroxide is not successful in removing organic matter from these soils.

3. The combined water was reduced on the average by about twenty per cent by saturating the soils with calcium ions. Excluding the group of calcareous soils, the reduction on the remainder was 34·7 per cent. The reduction is attributed to the fact that sour soils on ignition lose water by combination of exchangeable hydrogen and hydroxyl ions from the alumino-silicate crystal lattice framework. If this exchangeable H′ is replaced by calcium, such loss cannot occur.

4. Sticky Point moisture appears to vary with organic carbon and combined water (or loss on ignition) so long as calcium is the only replaceable base. Under these conditions r L 1. S P $= 0{\cdot}8672$ and the Sticky Point moisture may be calculated with fair accuracy from the equation

$$SP = 2\ 637\ L\ 1 + 23{\cdot}98$$

The equation is not very accurate for very sandy soils and may fail if the soils have very high or very low $\frac{SiO_2}{R_2O_3}$ ratios.

5. Although *R* varies with combined water to a great extent as in the case of *SP*, it appears to depend largely upon base-exchange capacity or values known to be related to the base-exchange capacity. Carbonates and the $\frac{SiO_2}{R_2O_3}$ ratio may also affect *R* and further examination of this value is required.

Professor P. C. Mahalanobis has pointed out that application of the method of analysis of variance offers advantages in studying the relative importance of the various parameters at each stage of the correlational analysis. Owing to his transfer to other work the writer has had no opportunity to re-examine the work on these lines. Mr. E. G. Lewis, Lecturer in Mathematics, Rangoon University, has independently repeated the examination of the data for untreated and calcium soils utilizing the method of analysis of variance. His results check those quoted in the paper so closely that the regression equations are practically identical. To these two gentlemen, as well as to several assistants in the chemical section of the Agricultural College, Mandalay, the writer desires to express his thanks and particularly to Mr. M. Menon, B.A., who has devoted a great deal of his own time to checking of arithmetical work.

It would have been of advantage had the standard error of the regression coefficients been calculated. Unfortunately, for reasons previously stated, the writer is unable to devote any more time to the subject and the paper has necessarily to be published in its present form.

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Appendix

TABLE I

Original soils

Soil No.	Clay equivalent	CO_2 as carbonate	Organic carbon	Combined water	$\frac{SiO_2}{R_2O_3}$ (Molr.)	$\frac{SiO_2}{Al_2O_3}$ (Molr.)	*BEC*	*S P* water	*R*
Hmawbi good 0-6" . .	31·01	0·03	0·980	2·528	2·48	2·71	10·50	41·23	2·099
B 610	56·17	0·04	1·558	9·797	2·16	2·62	21·00	43·95	4·435
B 616 . . .	67·59	0·04	2·198	11·454	2·22	2·56	27·83	49·03	5·537
B 618	49·81	0·06	1·784	8·176	2·40	2·90	20·17	43·66	3·869
B 624	22·80	0·04	0·904	2·946	2·61	2·93	5·42	22·85	1·328
B 951	75·85	0·07	2·763	7·706	1·57	1·99	19·75	49·47	3·937

TABLE I—*contd.*

Soil No.	Clay equivalent	CO_2 as carbonate	Organic carbon	Combined water	$\frac{SiO_2}{R_2O_3}$ (Molr.)	$\frac{SiO_2}{Al_2O_3}$ (Molr.)	*BEC*	*S P* water	*R*
B 957	73·66	0·10	2·915	4·680	1·85	2·26	19·83	53·28	3·905
B988	37·99	0·03	1·306	2·545	2·05	2·51	7·92	34·38	1·576
B 992	50·85	0·02	1·753	2·963	2·55	3·19	14·66	44·32	2·528
B999	36·86	0·02	1·501	2·241	2·60	3·21	11·83	34·75	1·581
B 1010	44·83	0·02	1·177	2·750	2·68	3·26	10·33	40·44	1·772
B 1015	44·00	0·04	1·637	3·664	2·42	2·89	8·67	41·81	1·903
B 1031	36·26	0·01	1·237	2·051	2·60	3·13	10·25	30·74	1·589
B 1129	22·50	0·04	1·646	8·847	1·55	1·77	9·17	48·53	2·506
B 1131	30·12	0·04	2·239	10·279	1·55	1·75	10·33	56·16	3·105
B 1133	32·39	0·07	1·015	11·545	1·90	2·25	13·00	55·48	3·177
B 1135	27·13	0·06	1·287	12·690	1·55	1·75	8·83	49·23	3·164
B 1137	20·30	0·04	1·080	4·426	1·42	1·62	7·42	34·12	1·351
B 1139	12·65	0·11	0·777	3·707	1·92	2·39	7·25	31·53	1·359
B 1141	9·70	0·02	0·556	2·719	1·80	2·25	5·42	27·95	0·993
B 1143	15·51	1·12	0·879	4·412	1·94	2·36	6·17	46·14	1·535
Nanda Tank	50·71	9·082	2·146	6·188	2·37	2·87	21·09	46·32	5·266
Mandalay 1	53·34	3·488	0·830	4·501	2·70	3·35	16·00	36·42	5·857
„ 10	65·71	2·887	0·633	5·549	2·49	3·02	27·50	40·84	6·418
„ 13	62·18	6·378	2·275	5·004	3·53	4·30	10·50	54·31	5·916
„ 21	34·34	1·101	1·137	5·183	2·11	2·58	20·08	41·78	3·983
„ 27	46·07	6·733	1·295	3·965	2·19	2·59	15·67	37·52	3·339
„ 28	56·01	1·207	0·890	2·672	2·38	2·88	27·67	38·00	5·473
„ 33	41·50	2·399	0·935	3·970	2·35	2·90	16·17	34·34	3·436
„ 34	39·51	1·134	0·684	4·706	2·37	2·90	19·00	30·94	3·597
„ 35	51·62	1·025	1·007	4·029	2·14	2·59	22·08	34·62	4·528
„ 36	54·04	0·871	0·933	3·984	2·03	2·48	23·58	36·38	4·623
„ 38	41·57	4·094	0·341	4·480	2·01	2·43	14·67	32·15	3·353
Old 28	52·28	6·360	2·644	5·763	1·99	2·36	22·50	38·33	4·656
Old 57	68·69	4·160	4·017	4·346	3·43	4·28	11·17	63·80	6·270
Singairg 1	34·49	3·012	0·894	2·285	2·17	2·74	11·50	37·87	1·826
„ 2	33·95	2·240	0·556	2·169	2·41	2·97	13·33	32·39	2·187
„ 3	52·89	2·764	0·721	1·909	2·56	3·15	19·33	37·18	3·724
Means	43·08	1·604	1·398	5·074	2·24	2·70	14·94	40·85	3·361

TABLE II

$CaCl_2$ treated soils

Soil No.	CO_2 as carbonate	Organic carbon	Combined water	Sticky point water	*R*
Hmawbi Good	0·09	0·920	2·032	38·05	2·292
610	0·03	1·520	3·549	46·72	4·434
616	0·06	2·182	4·130	51·67	5·542
618	0·07	1·724	4·941	44·31	3·815
624	0·01	0·899	1·749	21·15	1·141
951	0·13	3·364	8·574	51·49	4·722
957	0·11	2·900	6·427	53·85	4·175
988	0·05	1·231	2·482	33·41	2·025
992	0·17	1·625	3·336	42·26	2·921
999	0·04	1·473	2·420	38·30	2·062
1010	0·08	1·073	2·466	38·56	1·782
1015	0·05	1·624	2·946	40·19	1·908
1031	0·04	1·197	2·867	33·72	1·535
1129	0·04	1·660	5·125	47·37	2·191
1131	0·11	2·162	6·099	54·87	2·750
1133	0·04	1·834	5·124	50·88	2·861
1135	0·06	2·321	6·750	47·03	2·783
1137	0·11	1·021	2·208	34·05	1·337
1139	0·08	0·833	2·457	31·85	1·203
1141	0·07	0·539	1·689	27·93	0·891
1143	1·10	0·936	2·368	34·27	1·339
N. T.	9·11	3·135	4·450	47·16	4·999
Mandalay 1	3·94	1·190	4·628	41·36	5·265
„ 10	2·99	0·912	5·815	45·00	6·508
„ 13	7·14	1·763	7·375	55·32	5·663
„ 21	1·20	1·808	4·323	41·85	3·830
„ 27	7·03	1·555	3·251	37·64	3·195
„ 28	1·28	1·208	3·605	44·80	5·407
„ 33	2·38	1·069	3·936	38·41	3·399
„ 34	1·28	0·696	2·305	32·22	3·635
„ 35	1·54	1·249	3·222	40·32	4·457
„ 36	1·15	0·958	5·017	40·81	4·532
„ 38	4·46	0·599	3·725	34·65	3·257
Old 28	6·33	2·304	5·445	45·84	4·988
Old 57	5·81	3·158	6·618	65·94	6·825
Singaing 1	3·19	0·841	3·324	38·56	2·421
„ 2	2·47	0·523	2·283	32·78	2·558
„ 3	3·29	0·593	3·433	40·16	4·279
Means	1·77	1·489	4·013	41·70	3·393

TABLE III

NaBrO treated calcium soils

Soil No.	CO_2 as carbonate	Organic carbon	Combined water	Sticky point moisture	*R*
Hmawbi good 0-6″ . .	0·18	0·486	2·342	37·90	2·026
B 610 . . .	0·34	0·729	4·510	46·48	4·226
B 616 . . .	0·30	1·175	5·161	50·91	5·279
B 618 . . .	0·21	0·923	3·846	42·00	3·746
B 624 . . .	0·10	0·427	1·200	23·87	1·047
B 951 . . .	0·42	2·533	5·865	48·58	4·100
B 957 . . .	0·41	2·208	5·264	53·05	3·849
B 988 . . .	0·20	0·717	2·399	31·23	1·659
B 992 . . .	0·22	1·079	2·643	40·10	2·576
B 999 . . .	0·19	0·922	1·508	32·75	1·749
B 1010 . . .	0·15	0·674	2·488	38·04	1·905
B 1015 . . .	0·15	1·125	3·174	39·53	2·120
B 1031 . . .	0·59	0·338	3·953	29·98	1·590
B 1129 . . .	0·20	1·223	5·064	45·66	2·503
B 1131 . . .	0·19	1·783	6·063	51·72	3·195
B 1133 . .	0·19	1·471	4·805	52·48	3·221
B 1135 . . .	0·27	1·883	5·723	46·52	3·219
B 1137 . . .	0·11	0·707	1·852	32·42	1·370
B 1139 . . .	0·22	0·508	1·965	29·83	1·165
B 1141 . . .	0·13	0·300	1·451	23·65	0·753
B 1143 . . .	1·22	0·630	2·062	32·19	1·208
Nanda Tank . . .	9·75	1·148	5·910	43·77	4·293
Mandalay 1 . . .	4·38	0·511	3·976	41·05	5·152
„ 10 . . .	3·18	0·399	4·681	46·47	5·995
„ 13 . . .	7·34	0·694	6·178	55·61	5·262
„ 21 . . .	1·44	0·812	3·728	38·96	3·149
„ 27 . . .	7·01	0·756	3·240	36·19	2·793
„ 28 . . .	1·52	0·506	3·582	42·20	4·481
„ 33 . . .	2·87	0·396	4·179	34·48	2·665
„ 34 . . .	1·43	0·333	2·719	31·34	2·842
„ 35 . . .	1·30	0·513	3·364	39·19	3·568
„ 36 . . .	1·17	0·486	3·930	37·18	3·794
„ 38 . . .	4·23	0·380	3·706	33·22	3·195
Old 28 . . .	6·76	0·679	4·675	44·50	4·031
Old 57 . . .	6·22	1·093	5·691	63·86	5·719
Singaing 1 . . .	3·42	0·299	3·034	34·45	2·029
„ 2 . . .	2·75	0·230	2·760	31·83	2·449
„ 3 . . .	3·11	0·376	3·304	40·44	4·010
Means	1·944	0·828	3·737	40·10	3·104

TABLE IV

Original soils (untreated)

(*A*) *SP* Correlations	(*B*) *R* Correlations
Put *SP* = 1	Put *R* = 1
CE = 2	*CE* = 2
CO_2 = 3	CO_2 = 3
Organic carbon = 4	Organic carbon = 4
CW = 5	*CW* = 5
BEC = 6	*BEC* = 6
$\frac{SiO_2}{R_2O_3}$ = 7	$\frac{SO}{R_2O_3}$ = 7

A

$r_{12} = 0{\cdot}4468$ $r_{23} = 0{\cdot}2592$ $r_{34} = 0{\cdot}1835$ $r_{45} = 0{\cdot}3471$ $r_{56} = 0{\cdot}2004$
$r_{67} = 0{\cdot}03922$

$r_{13} = 0{\cdot}09683$ $r_{24} = 0{\cdot}5720$ $r_{35} = -0{\cdot}1405$ $r_{46} = 0{\cdot}1109$ $r_{57} = -0{\cdot}4072$

$r_{14} = 0{\cdot}7447$ $r_{25} = 0{\cdot}1629$ $r_{36} = 0{\cdot}2297$ $r_{47} = 0{\cdot}1603$

$r_{15} = 0{\cdot}6112$ $r_{26} = 0{\cdot}7266$ $r_{37} = 0{\cdot}3384$

$r_{16} = 0{\cdot}1136$ $r_{27} = 0{\cdot}3496$

$r_{17} = -0{\cdot}1629$

$r_{12{\cdot}34567} = 0{\cdot}4041$

$r_{13{\cdot}24567} = 0{\cdot}2374$

$r_{14{\cdot}23567} = 0{\cdot}4126$

$r_{15{\cdot}23467} = 0{\cdot}5204$

$r_{16{\cdot}23457} = -0{\cdot}3859$

$r_{17{\cdot}23456} = -0{\cdot}3950$

B

$r_{12} = 0{\cdot}7947$ $r_{23} = 0{\cdot}2892$ $r_{34} = 0{\cdot}1835$ $r_{45} = 0{\cdot}3471$ $r_{56} = 0{\cdot}2004$
$r_{67} = 0{\cdot}03922$

$r_{13} = 0{\cdot}4599$ $r_{24} = 0{\cdot}5720$ $r_{35} = -0{\cdot}1405$ $r_{46} = 0{\cdot}1109$ $r_{57} = -0{\cdot}4072$

$r_{14} = 0{\cdot}4299$ $r_{25} = 0{\cdot}1629$ $r_{36} = 0{\cdot}2297$ $r_{47} = 0{\cdot}1603$

$r_{15} = 0{\cdot}3570$ $r_{26} = 0{\cdot}7266$ $r_{37} = 0{\cdot}3384$

$r_{16} = 0{\cdot}7546$ $r_{27} = 0{\cdot}3496$

$r_{17} = 0{\cdot}3172$

$r_{12{\cdot}34567} = 0{\cdot}2652$

$r_{13\cdot24567} = 0\cdot5208$

$r_{14\cdot23567} = 0\cdot03149$

$r_{15\cdot23467} = 0\cdot6214$

$r_{16\cdot23457} = 0\cdot4974$

$r_{17\cdot23456} = 0\cdot4839$

TABLE V

$CaCl_2$ treated soils

(*A*) *SP* Correlations	(*B*) *R* Correlations
Put *SP* = 1	Put *R* = 1
CE = 2	*CE* = 2
CO_2 = 3	CO_2 = 3
Organic carbon = 4	Organic carbon = 4
CW = 5	*CW* = 5
BEC = 6	*BEC* = 6
$\frac{SiO_2}{R_2O_3}$ = 7	$\frac{SiO_2}{R_2O_3}$ = 7

A

$r_{12} = 0\cdot6555$ $r_{23} = 0\cdot3200$ $r_{34} = 0\cdot2260$ $r_{45} = 0\cdot7210$ $r_{56} = 0\cdot3367$
$r_{67} = 0\cdot03922$

$r_{13} = 0\cdot2453$ $r_{24} = 0\cdot5250$ $r_{35} = 0\cdot2596$ $r_{46} = 0\cdot2211$ $r_{57} = -0\cdot0370$

$r_{14} = 0\cdot7695$ $r_{25} = 0\cdot6156$ $r_{36} = 0\cdot2174$ $r_{47} = -0\cdot07098$

$r_{15} = 0\cdot8139$ $r_{26} = 0\cdot7266$ $r_{37} = 0\cdot3974$

$r_{16} = 0\cdot3697$ $r_{27} = 0\cdot3496$

$r_{17} = 0\cdot1264$

$r_{12\cdot34567} = -0\cdot01485$

$r_{13\cdot24567} = -0\cdot1559$

$r_{14\cdot23567} = 0\cdot4910$

$r_{15\cdot23467} = 0\cdot5483$

$r_{16\cdot23457} = 0\cdot1511$

$r_{17\cdot23456} = 0\cdot2924$

B

$r_{12} = 0{\cdot}8652$ $r_{23} = 0{\cdot}3200$ $r_{34} = 0{\cdot}2260$ $r_{45} = 0{\cdot}7210$ $r_{56} = 0{\cdot}3367$
$r_{67} = 0{\cdot}03922$

$r_{13} = 0{\cdot}4923$ $r_{24} = 0{\cdot}5250$ $r_{35} = 0{\cdot}2596$ $r_{46} = 0{\cdot}2211$ $r_{57} = -0{\cdot}0370$

$r_{14} = 0{\cdot}4520$ $r_{25} = 0{\cdot}6156$ $r_{36} = 0{\cdot}2174$ $r_{47} = -0{\cdot}07098$

$r_{15} = 0{\cdot}6549$ $r_{26} = 0{\cdot}7266$ $r_{37} = 0{\cdot}3974$

$r_{16} = 0{\cdot}7739$ $r_{27} = 0{\cdot}3496$

$r_{17} = 0{\cdot}3676$

$r_{12{\cdot}34567} = 0{\cdot}1760$

$r_{13{\cdot}24567} = 0{\cdot}3843$

$r_{14{\cdot}23567} = -0{\cdot}06015$

$r_{15{\cdot}23467} = 0{\cdot}6442$

$r_{16{\cdot}23457} = 0{\cdot}7137$

$r_{17{\cdot}23456} = 0{\cdot}5319$

TABLE VI

NaBrO treated calcium soils

(*A*) *SP* Correlations	(*B*) *R* Correlations
Put *SP* = 1	Put *R* = 1
CE = 2	*CE* = 2
CO_2 = 3	CO_2 = 3
Organic carbon = 4	Organic carbon = 4
CW = 5	*CW* = 5
BEC = 6	*BEC* = 6
$\frac{SiO_2}{R_2O_3}$ = 7	$\frac{SiO_2}{R_2O_3}$ = 7

A

$r_{12} = 0{\cdot}6790$ $r_{23} = 0{\cdot}2984$ $r_{34} = -0{\cdot}2213$ $r_{45} = 0{\cdot}5822$ $r_{56} = 0{\cdot}4030$
$r_{67} = 0{\cdot}03922$

$r_{13} = 0{\cdot}2342$ $r_{24} = 0{\cdot}3192$ $r_{35} = 0{\cdot}3343$ $r_{46} = 0{\cdot}02301$ $r_{57} = -0{\cdot}009638$

$r_{14} = 0{\cdot}6005$ $r_{25} = 0{\cdot}6028$ $r_{36} = 0{\cdot}2288$ $r_{47} = -0{\cdot}3987$

$r_{15} = 0{\cdot}8679$ $r_{26} = 0{\cdot}7266$ $r_{37} = 0{\cdot}4111$

$r_{16} = 0{\cdot}3863$ $r_{27} = 0{\cdot}3496$

$r_{17} = 0{\cdot}1402$

$r_{12{\cdot}34567} = 0{\cdot}07427$

$r_{13{\cdot}24567} = -0{\cdot}1248$

$r_{14{\cdot}23567} = 0{\cdot}3145$

$r_{15{\cdot}23467} = 0{\cdot}6904$

$r_{16{\cdot}23457} = 0{\cdot}07186$

$r_{17{\cdot}23456} = 0{\cdot}3320$

B

$r_{12} = 0{\cdot}8448$ $r_{23} = 0{\cdot}2984$ $r_{34} = -0{\cdot}2213$ $r_{45} = 0{\cdot}5822$ $r_{56} = 0{\cdot}4030$
$r_{67} = 0{\cdot}03922$

$r_{13} = 0{\cdot}4547$ $r_{24} = 0{\cdot}3192$ $r_{35} = 0{\cdot}3343$ $r_{46} = 0{\cdot}02301$ $r_{57} = -0{\cdot}009638$

$r_{14} = 0{\cdot}2161$ $r_{25} = 0{\cdot}6028$ $r_{36} = 0{\cdot}2288$ $r_{47} = -0{\cdot}3987$

$r_{15} = 0{\cdot}7517$ $r_{26} = 0{\cdot}7266$ $r_{37} = 0{\cdot}4111$

$r_{16} = 0{\cdot}7290$ $r_{27} = 0{\cdot}3496$

$r_{17} = 0{\cdot}3101$

$r_{12{\cdot}34567} = 0{\cdot}3445$

$r_{13{\cdot}24567} = 0{\cdot}1015$

$r_{14{\cdot}23567} = -0{\cdot}1845$

$r_{15{\cdot}23467} = 0{\cdot}6613$

$r_{16{\cdot}23457} = 0{\cdot}3642$

$r_{17{\cdot}23456} = 0{\cdot}1949$

TABLE VII-A

Sticky Point moisture—actual and calculated values

Soil No.	Original soils			$CaCl_2$ treated soils					NaBrO treated Ca soils				
	Actual S. P.	Calculated S. P. (Equation A1)	Difference Col. 2—Col. 3	Actual S. P.	Calculated S. P. [Equation A2(*a*)]	Difference Col. 5—Col. 6	Calculated S. P. [Equation, A2 (*b*)]	Difference Col. 5—Col. 8	Actual S. P.	Calculated S. P. [Equation A3(*a*)]	Difference Col. 10—Col. 11	Calculated S. P. [Equation A3(*b*)]	Difference Col. 10—Col. 13
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Hmawbi 0-6" .	41·23	35·11	+6·12	38·05	34·45	+3·60	34·52	+3·53	37·90	33·90	+4·00	34·12	+3·78
B 610 . .	43·95	48·76	—4·81	46·72	40·29	+6·43	40·36	+6·36	46·48	42·20	+4·28	41·79	+4·69
B 616 . .	49·03	54·02	—4·99	51·67	45·04	+6·43	45·26	+6·41	50·91	47·73	+3·18	47·59	+3·32
B 618 . .	43·66	47·28	—3·62	44·31	45·82	—1·51	45·79	—1·48	42·00	42·02	—0·02	42·14	—0·14
B 624 . .	22·85	36·19	—13·34	21·15	33·99	—12·84	34·09	—12·94	23·87	29·71	—5·84	30·30	—6·43
B 951 . .	49·47	52·99	—3·52	51·49	60·52	—9·03	60·55	—9·06	48·58	54·56	—5·98	55·28	—6·70
B 957 . .	53·28	49·25	+4·03	53·85	53·41	+0·44	53·57	+0·28	53·05	51·90	+1·15	52·62	+0·43
B 988 . .	34·38	37·50	—3·12	33·41	35·70	—2·29	35·81	—2·40	31·23	32·96	—1·73	33·20	—1·97
B 992 . .	44·32	41·03	+3·29	42·26	41·42	+0·84	41·56	+0·70	40·10	38·92	+1·18	39·68	+0·42
B 999 . .	34·75	37·83	—3·08	38·30	38·37	—0·07	38·58	—0·28	32·75	33·72	—0·97	34·72	—1·97
B 1010 . .	40·44	38·73	+1·71	38·56	36·97	+1·59	37·04	+1·52	38·04	36·73	+1·31	37·17	+0·87
B 1015 . .	41·81	42·28	—0·47	40·19	39·92	+0·27	40·11	+0·08	39·53	40·57	—1·04	41·14	—1·61
B 1031 . .	30·74	36·65	—5·91	33·72	38·38	—4·66	38·43	—4·71	29·98	40·26	—10·28	39·85	—9·87
B 1129 . .	48·53	45·68	+2·85	47·37	43·32	+4·05	43·23	+4·14	45·66	43·72	+1·94	43·36	+2·30
B 1131 . .	56·16	51·50	+4·66	54·87	48·25	+6·62	48·20	+6·67	51·72	50·96	+0·76	50·84	+0·88
B 1133 . .	55·48	47·72	+7·76	50·88	45·22	+5·66	45·19	+5·69	52·48	46·12	+6·36	42·26	+6·22
B 1135 . .	49·23	50·73	—1·50	47·03	50·76	—3·73	50·68	—3·65	46·52	50·16	—3·64	50·25	—3·73
B 1137 . .	34·12	35·83	—1·71	34·05	31·99	+2·06	32·05	+2·00	32·42	27·04	+5·38	27·15	+5·27
B 1139 . .	31·53	33·38	—1·85	31·85	33·44	—1·59	33·42	—1·57	29·83	29·26	+0·57	29·37	+0·46

TABLE VII-A—*contd.*

Soil No.	Original soils			$CaCl_2$ treated soils					NaBrO treated Ca soils				
	Actual S. P.	Calculated S. P. (Equation A1)	Difference Col. 2—Col. 3	Actual S. P.	Calculated S. P. [Equation A2(*a*)]	Difference Col. 5—Col. 6	Calculated S. P. [Equation, A2(*b*)]	Difference Col. 5—Col. 8	Actual S. P.	Calculated S. P. [Equation A3(*a*)]	Difference Col. 10—Col. 11	Calculated S. P [Equation A3(*b*)]	Difference Col. 10—Col. 13
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
B 1141 . .	27·95	30·64	—2·69	27·93	29·62	—1·69	29·60	—1·67	23·65	25·30	—1·65	25·30	—1·65
B 1143 . .	46·14	35·76	+10·38	34·27	33·72	+0·55	33·74	+0·53	32·19	30·46	+1·73	30·67	+1·52
Nanda Tank .	46·32	45·66	+0·66	47·16	50·66	—3·50	51·16	—4·00	43·77	51·47	—7·70	51·13	—7·36
Mandalay 1 . .	36·42	39·17	—2·75	41·36	43·54	—2·18	43·37	—2·01	41·05	41·92	—0·87	41·73	—0·68
„ 10 .	40·84	37·38	+3·46	45·00	44·91	+0·09	44·49	+0·51	46·47	42·91	+3·56	42·27	+4·20
„ 13 .	54·31	51·83	+2·48	55·32	56·35	—1·03	56·03	—0·71	55·61	56·68	—1·07	56·33	—0·72
„ 21 .	41·78	36·70	+5·08	41·85	43·56	—1·71	43·62	—1·77	38·96	39·22	—0·26	39·14	—0·18
„ 27 .	37·52	38·62	—1·10	37·64	39·72	—2·08	39·84	—2·20	36·19	37·39	—1·20	37·46	—1·27
„ 28 .	38·00	32·51	+5·49	44·80	39·76	+5·04	39·72	+5·08	42·20	38·45	+3·75	38·23	+3·97
„ 33 .	34·34	36·47	—2·13	38·41	39·96	—1·55	39·84	—1·43	34·48	40·06	—5·58	39·51	—5·03
„ 34 .	30·94	35·30	—4·36	32·22	33·86	—1·64	33·81	—1·59	31·34	33·91	—2·57	33·80	—2·46
„ 35 .	34·62	35·90	—1·28	40·32	38·12	+2·20	38·14	+2·18	39·19	36·22	+2·97	35·96	+3·23
„ 36 .	36·38	35·06	+1·32	40·81	41·43	—0·62	41·12	—0·31	37·18	37·71	—0·53	37·19	—0·01
„ 38 .	32·15	34·07	—1·92	34·65	36·20	—1·55	35·93	—1·28	33·22	36·08	—2·86	35·52	—2·30
Old 28 .	38·33	46·34	—8·01	45·84	48·49	—2·65	48·57	—2·73	44·50	41·59	+2·91	41·01	+3·49
„ 57 .	63·80	59·77	+4·03	65·94	60·15	+5·79	60·40	+5·54	63·86	56·42	+7·44	56·59	+7·27
Singaing 1 .	37·87	33·74	+4·13	38·56	36·68	+1·88	36·55	+2·01	34·45	33·83	+0·62	33·49	+0·96
„ 2 .	32·39	31·79	+0·60	32·78	33·15	—0·37	33·05	—0·27	31·83	33·72	—1·89	33·51	—1·68
„ 3 .	37·18	33·08	+4·10	40·16	37·13	+3·03	36·90	+3·26	40·44	37·63	+2·81	37·45	+2·99

TABLE VII-B

Values of R—*actual and calculated*

Soil No.	Original soils			$CaCl_2$ treated soils			Na BrO treated calcium soils				
	Actual R	Calculated R (Equation B1)	Difference Col. 2—Col. 3	Actual R	Calculated R (Equation B2)	Difference Col. 5—Col. 6	Actual R	Calculated R (Equation B3a)	Difference Col. 8 — Col. 9	Calculated R (Equation B3b)	Difference Col. 8—Col. 11
1	2	3	4	5	6	7	8	9	10	11	12
Hmawbi 0-6 in.	2·099	2·212	—0·113	2·292	2·064	+0·228	2·026	1·895	+0·131	2·085	—0·059
B 610	4·435	4·854	—0·419	4·434	3·817	+0·617	4·226	4·191	+0·035	4·094	+0·132
B 616	5·537	6·269	—0·732	5·542	5·078	+0·464	5·279	5·224	+0·055	5·182	+0·097
B 618	3·869	4·709	—0·840	3·815	4·476	—0·661	3·746	3·675	+0·071	3·812	—0·066
B 624	1·328	1·746	—0·418	1·141	1·352	—0·211	1·047	0·871	+0·176	1·092	—0·045
B 951	3·937	3·450	+0·487	4·722	4·981	—0·259	4·100	5·276	—1·176	4·408	—0·308
B 957	3·905	3·191	+0·714	4·175	4·449	—0·274	3·849	4·970	—1·121	4·315	—0·466
B 988	1·576	1·275	+0·301	2·025	1·433	+0·592	1·659	1·980	—0·321	1·630	+0·029
B 992	2·528	2·994	—0·466	2·921	3·236	—0·315	2·576	2·888	—0·312	2·970	—0·394
B 999	1·581	2·499	—0·918	2·062	2·517	—0·455	1·749	1·823	—0·074	1·950	—0·201
B 1010	1·772	2·498	—0·726	1·782	2·405	—0·623	1·905	2·375	—0·470	2·452	—0·547
B 1015	1·903	2·114	—0·211	1·908	2·088	—0·180	2·120	2·525	—0·405	2·433	—0·313
B 1031	1·589	2·229	—0·640	1·535	2·463	—0·928	1·590	2·694	—1·104	3·008	—1·418
B 1129	2·506	2·142	+0·364	2·191	2·121	+0·070	2·503	2·636	—0·143	2·486	+0·017
B 1131	3·105	2·615	+0·490	2·750	2·667	+0·083	3·195	3·357	—0·162	3·162	+0·033
B 1133	3·177	3·739	—0·562	2·861	3·018	—0·157	3·221	3·083	+0·138	3·075	+0·146
B 1135	3·164	2·919	+0·245	2·783	2·696	+0·087	3·219	3·036	+0·183	2·832	+0·387
B 1137	1·351	0·773	+0·578	1·337	0·631	+0·706	1·370	1·177	+0·193	0·627	+0·743
B 1139	1·359	1·370	—0·011	1·203	1·200	+0·003	1·165	0·973	+0·192	0·975	+0·190
B 1141	0·993	0·620	+0·373	0·891	0·524	+0·367	0·753	0·563	+0·190	0·436	+0·317

TABLE VII-B—*contd.*

Soil No.	Original soils			$CaCl_2$ treated soils			NaBrO treated calcium soils				
	Actual R	Calculated R (Equation B1)	Difference Col. 2—Col. 3	Actual R	Calculated R (Equation B2)	Difference Col. 5—Col. 6	Actual R	Calculated R (Equation B3a)	Difference Col. 8—Col. 9	Calculated R (Equation B3)	Difference Col. 8—Col. 11
1	2	3	4	5	6	7	8	9	10	11	12
B 1143	1·535	1·476	+0·059	1·339	1·139	+0·200	1·208	1·036	+0·172	0·976	+0·232
Nanda Tank	5·266	6·018	—0·752	4·999	5·341	—0·342	4·293	4·591	—0·298	4·894	—0·601
Mandalay 1	5·857	4·345	+1·512	5·265	4·469	+0·796	5·152	3·584	+1·568	3·788	+1·364
„ 10	6·418	5·834	+0·584	6·508	6·255	+0·253	5·995	4·952	+1·043	5·108	+0·887
„ 13	5·916	5·288	+0·628	5·663	5·904	—0·241	5·262	4·414	+0·848	5·132	+0·130
„ 21	3·983	3·861	+0·122	3·830	4·055	—0·225	3·149	3·139	+0·010	3·348	—0·199
„ 27	3·339	4·097	—0·758	3·195	3·709	—0·514	2·793	3·041	—0·248	2·917	—0·124
„ 28	5·473	4·792	+0·681	5·407	5·143	+0·264	4·481	4·217	+0·264	4·388	+0·093
„ 33	3·436	3·594	—0·158	3·399	3·713	+0·286	2·665	3·307	—0·642	3·497	—0·832
„ 34	3·597	3·954	—0·357	3·635	3·397	+0·238	2·842	2·828	+0·014	3·018	—0·176
„ 35	4·528	3·928	+0·600	4·457	3·985	+0·472	3·568	3·653	—0·085	3·558	+0·010
„ 36	4·623	3·960	+0·663	4·532	4·735	—0·203	3·794	4·048	—0·254	3·908	—0·114
„ 38	3·353	3·345	+0·008	3·257	3·296	—0·039	3·195	3·028	+0·167	2·868	+0·327
Old 28	4·656	5·131	—0·475	4·988	5·250	—0·262	4·031	4·227	—0·196	4·129	—0·098
„ 57	6·270	4·607	+1·663	6·825	5·469	+1·356	5·719	4·462	+1·257	4·953	+0·766
Singaing 1	1·826	2·435	—0·609	2·421	2·717	—0·296	2·029	2·344	—0·315	2·309	—0·280
„ 2	2·187	2·851	—0·674	2·558	2·744	—0·186	2·449	2·327	+0·122	2·515	—0·066
„ 3	3·724	3·952	—0·228	4·279	4·278	+0·001	4·010	3·502	+0·512	3·632	+0·378

TABLE VIII

Differences between actual and calculated values for S. P. *and* R

Error in *S. P.*	Untreated soils	Calcium soils		NaBrO treated calcium soils	
	[Equation A1]	(*a*) [Equation A (2) (*a*)]	(*b*) [Equation A(2) (*b*)]	(*a*) [Equation A(3) (*a*)]	(*b*) [Equation A(3) (*b*)]
Less than 10 per cent	25	31	30	29	29
10-20 per cent	11	6	7	7	7
20 per cent	2	1	1	2	2
Error in *R*	Untreated soils	Calcium soils		NaBrO treated calcium soils	
	[Equation B (1)]	[Equation B (2)]		(*a*) [Equation B(3) (*a*)]	(*b*) [Equation B (3) (*b*)]
Less than 10 per cent	11	21		19	20
10-20 per cent	15	11		10	12
20 per cent	12	6		9	6

RAPID DETERMINATION OF SOIL-MOISTURE BY DRYING THE SOIL OVER BUNSEN BURNER*

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In soil investigations it is often necessary to have a quick estimate of moisture with a fair amount of accuracy in soil samples brought fresh from the field. Methods† suggested by Bouyoucos [1926] and Nitzch [1927] for the rapid determination of soil moisture are one and the same in essence and consist in adding a definite volume of alcohol of known specific gravity to a definite weight of moist soil, shaking the mixture for a few minutes and finally determining the specific gravity of the semi-clear liquid obtained on standing or by filtration. These methods are based on the assumption that all the moisture in the soil goes to dilute the added alcohol the specific gravity of which is not affected in any other way.

The author tried this alcohol method on a number of heavy Rothamsted soils in connection with another investigation reported elsewhere [1932] in which a rapid determination of moisture content in a number of fresh soil samples had to be made almost daily for eighteen months. It was found that in the majority of cases the percentage of moisture obtained by the alcohol method was lower than the oven-dried percentage by more than 1·5 per cent and in some cases by five to seven per cent if the soil happened to be very sticky‡. The shaking of mixture of alcohol and soil in an end-over-end-shaker from thirty minutes to one hour gave better results, but the values were still more than 1-1·5 per cent too low. Shaking for longer periods was not tried for obvious reasons.**

* This work was carried out at the Rothamsted Experimental Station while the author was in England during 1927-29. Owing to pressure of work he could not write out and communicate the paper for publication so long.

† Recently Obaton [1935] has elaborated a rapid method for determining soil moisture from the measurement of electrical resistance in soil using alternating current. Complications arising out of the presence of varying amount and nature of colloidal materials in soil are, however, likely to make this method unsuitable for general use. Obaton himself observed that colloid soil behaved differently from sandy soil.

‡ Later on Smith and Flint [1930] also tried the alcohol method and found it to be unreliable for fine textured soils and those containing alkali.

** Bouyoucos [1931] subsequently admitted the defect in his original method and tried to improve it by introducing mechanical dispersion of soil by a motor-driven stirrer.

If therefore became necessary to try other methods and the possibility of drying the soil directly over Bunsen burner was tested. A quantity of moist soil (between ten and fifteen grams. was found to be very convenient) was taken in a fused silica basin and placed over a rose burner (preferably a mushroom head as sold by Messrs. A Gallenkamp & Co. Ltd., specification No. 214) at a height of about two to three inches from the flames so as to have the heat evenly distributed at the bottom of the basin. The soil was constantly stirred and small clods broken, as drying proceeded, with thin metal rod having a glass or wooden handle. The colour of the soil changed due to loss of moisture and it was easy to detect when the soil was dry without burning it. After the soil was apparently dry it was still kept over the flame for half a minute or so to ensure complete loss of moisture. It takes three to six minutes for a soil to dry completely. It is advisable to remove the basin off the flame for about twenty seconds once or twice during the heating to avoid burning of the soil. It was found that percentages of moisture of the Rothamsted soils obtained in this way were seldom higher than those obtained by drying overnight in a steam oven at 98°-99° C. by more than one per cent. With a little practice the difference averaged round about 0·5 per cent by the two methods, the percentages by the Bunsen burner method being generally higher. It has been possible to determine moisture content of ten different soils weighing, drying, calculation etc., all complete in one hour and fifteen minutes. Table I below gives the percentages of several Rothamsted soils calculated on the dry basis and determined simultaneously by the three methods *viz.*, by drying over Bunsen burner, by drying in a steam oven for twenty-four hours, and by alcohol. All percentages of moisture by the alcohol method were determined after shaking the mixture of soil and alcohol vigorously for one minute and then filtering a portion of the supernatant liquid after half an hour's standing except those which are followed by the figure ($\frac{1}{2}$h.) or (1h.) in which case the mixture was shaken for half or one hour respectively.

TABLE I

Showing the comparison between percentages of moisture of several heavy Rothamsted soils as determined by three different methods

Soil No.	Percentage of moisture as determined by			Soil No.	Percentage of moisture as determined by		
	Drying over Bunsen burner	Drying in steam oven	Alcohol method		Drying over Bunsen burner	Drying in steam oven	Alcohol method
1	7·3	6·8	5·3	32	16·5	16·5	12·6
2	7·3	6·6	5·1	33	16·5	16·2	9·3
3	8·3	7·6	6·5	34	16·6	16·2	15·5 (1 h.)
4	9·1	8·5	8·2 ($\frac{1}{2}$ h.)	35	16·7	16·5	15·1
5	9·7	9·5	7·1 (1 h.)	36	16·8	15·9	11·7

TABLE I—*contd.*

Soil No.	Percentage of moisture as determined by			Soil No.	Percentage of moisture as determined by		
	Drying over Bunsen burner	Drying in steam oven	Alcohol method		Drying over Bunsen burner	Drying in steam oven	Alcohol method
6	9·7	9·0	7·0	37	17·0	16·7	14·8 (1 h.)
7	10·4	10·2	8·6	38	17·2	17·7	12·8
8	10·5	10·3	9·7 (1 h.)	39	17·4	16·9	14·7
9	11·0	11·0	9·9 (½ h.)	40	17·7	17·6	10·2
10	11·3	10·8	10·9 (½ h.)	41	17·7	17·5	15·2 (1 h.)
11	11·7	10·3	8·3	42	17·7	16·9	15·1
12	11·9	11·8	9·2 (1 h.)	43	18·1	18·3	14·1
13	11·9	11·2	8·1	44	18·3	17·5	12·5
14	12·1	11·3	7·9 (1 h.)	45	18·5	17·5	15·3
15	12·6	12·1	11·3	46	18·9	18·4	7·6
16	12·6	12·6	9·4	47	18·9	18·3	18·4 (1 h.)
17	13·0	12·9	10·3	48	19·7	20·6	13·8
18	13·4	13·1	12·3 (1 h.)	49	20·3	20·1	13·8
19	13·6	13·2	11·5	50	20·4	19·9	14·5
20	14·1	13·3	12·8 (½ h.)	51	20·5	20·9	19·6 (1 h.)
21	14·3	13·8	12·5	52	20·9	20·4	18·7 (1 h.)
22	14·5	14·9	14·1 (1 h.)	53	21·4	20·9	19·6
23	14·5	13·9	13·1 (1 h.)	54	22·4	22·7	12·7
24	15·1	14·5	10·4	55	22·8	22·3	20·5 (1 h.)
25	15·4	14·6	12·8	56	23·8	23·2	18·2
26	15·4	14·8	12·9	57	23·8	24·0	20·0 (1 h.)
27	15·6	16·3	15·0 (1 h.)	58	24·0	23·9	16·6
28	15·7	15·1	15·1 (1 h.)	59	26·9	25·6	18·8
29	15·8	15·8	13·4	60	26·9	25·3	17·9
30	15·9	14·9	13·0	61	27·6	26·3	27·3
31	16·0	15·8	14·5	62	29·4	28·2	19·9

It is evident from the above table that percentage of moisture obtained by drying directly over the Bunsen burner is on the average higher than that obtained by heating overnight in steam oven by 0·5 to 1·0 per cent until the moisture content of the soil exceeded twenty-five per cent when the difference was slightly greater than one per cent. It should be mentioned in this connection that the temperature of the steam oven averages between 98°-99° C. and consequently the percentage of moisture obtained by drying in the oven is lower than the standard percentage obtained by heating overnight at 105°C. So that the actual difference between the true oven-dried percentage and the percentage by drying over Bunsen burner will be much smaller as shown in Table III later on.

With sandy soil precisely the same results as above were observed ; but in this case fair agreement of the percentage by the alcohol method with that by the steam oven was obtained until the moisture content of the soil was higher than fourteen to fifteen per cent as will be seen in Table II below.

TABLE II

Showing the comparison between percentages of moisture in Woburn sandy soils as determined by the three different methods

Soil No.	Percentage of moisture as determined by			Soil No.	Percentage of moisture as determined by		
	Drying over Bunsen burner	Drying in steam oven	Alcohol method		Drying over Bunsen burner	Drying in steam oven	Alcohol method
1	5·3	5·4	5·4	7	12·1	13·4	12·1
2	5·8	6·2	5·8	8	13·3	12·9	12·8
3	6·7	7·0	6·4	9	15·0	14·4	12·7
4	8·5	9·3	9·1	10	15·2	14·7	12·9 (½ h.)
5	10·5	10·5	11·2	11	16·0	15·2	14·0 (½ h.)
6	11·7	11·3	11·1	12	18·1	17·4	14·6

Before proceeding further it is intended to discuss briefly the possibilities of error in the Bunsen burner method. This is specially desirable in view of the fact that the method in which the soil is heated directly over the flame may appear drastic at first sight.

From the point of view of heating, the soil can be resolved into four component parts *viz.*, inorganic matter, moisture, organic matter and combined water. The inorganic matter is unaffected by heat in so far as its mass is concerned. The moisture is driven off at 110°-130°C. The organic matter begins to be destroyed at temperatures above 110° C. but the destruction remains nominal until 170°-190°C. Upwards of 250° C. the loss in soil is mainly that of combined water. In the Bunsen burner method, therefore, no burning of organic matter or loss of combined water will take place until all the moisture is driven off, provided the soil is kept stirred and procedures followed as stated in the experimental details. After the soil is apparently dry it is still kept over the flame for half a minute or so to ensure complete loss of moisture. During this time the soil may be heated up to about 200°C. thereby causing some loss of organic matter, but that loss for the reason stated above, is nominal. However, to test this point further, five different soils containing varied amounts of organic matter were subjected to heating over Bunsen burner. These soils were available in the air-dried condition. Consequently they were taken in earthen pots and were exposed to changes in weather for about three weeks. Samples were collected from these pots a day after heavy rainfall. In addition to the Bunsen burner method the

percentage of moisture in these samples was determined by three other methods including the drying in air oven at 105°C. Results which are given in Table III below together with organic matter and clay content of the soils, show that the moisture given by the Bunsen burner method did not vary from the air oven dry moisture by more than one per cent.

TABLE III

Showing the comparison between percentages of moisture of five different soils as determined by various methods

Soil	Per cent organic matter	Per cent clay	Percentage of moisture as determined by			
			Drying over Bunsen burner	Drying in steam oven	Alcohol method	Drying in air-oven at 105° C.
Argentine .	3·4	..	19·3	18·5	15·8	19·0
Cheshire .	6·9	15·3	29·0	28·3	24·5	29·2
Sudan .	4·3	49·5	46·0	45·3	22·2 35·6 (1 h.)	46·9
Fiji .	11·4	31·3	52·1	50·3	40·1	53·0
Fenn .	37·0	23·0	73·8	72·0	47·3	74·9

It will thus appear that in soil investigations where a rapid and fairly accurate determination of the moisture content of a soil of any type is wanted the Bunsen burner method as described here will be found suitable. The method, however, is not intended for use in investigations where absolute accuracy in the percentage of moisture is required.

SUMMARY

(1) The possibility of a rapid determination of moisture content of soils by quickly drying the soil over a Bunsen burner was tried and the method as described in this note was found suitable for all types of soil.

(2) The alcohol method for the rapid determination of soil moisture as suggested by Bouyoucos and also by Nitzch was not found suitable for heavy soils.

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STUDIES ON THE ORGANIC NITROGEN OF PADDY SOILS

PART I. DISTRIBUTION OF "HUMIC" AND "NON-HUMIC" NITROGEN IN ORGANIC MATTER

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The practice of maintaining swamp condition in the paddy fields for months during the growth of the crop provides an excellent opportunity of studying the influence of widely-varying and long-continued cultural treatment on the organic matter of the soils. Ever since paddy was grown on them first, these soils have remained alternately dry and water-logged nearly for equal periods, and consequently in such soils, the decomposition of the added plant and animal residues and the further decomposition of the humic matter itself have proceeded under conditions different from those obtaining in normal agricultural soils. It was thought that this difference in treatment might have brought about considerable differences in the nature of the organic matter of the soils and one of the objects of the present investigation is to ascertain whether the organic nitrogen compounds of the paddy soils are different in nature from those occurring in dry cultivated soils (soils not liable to long and frequent water-logging).

Information on the nature of the organic nitrogen compounds of the paddy soils is further required to study the part played by them in the nutrition of paddy. Extensive experiments on the changes of ammonia in paddy soils carried out in this laboratory have shown that although soon after water-logging, the ammonia content of the soils increases, the level drops down shortly so that during the period of the active vegetative growth of the crop, soils contain little or no ammonia. It is believed that at this stage plants assimilate nitrogen in organic forms.

The organic nitrogen of the soils can be fractionated into parts by treating with cold, dilute caustic soda. The scheme of fractionation and the nomenclature employed in this paper are same as those adopted by Hobson and Page [1932] in the study of the organic matter of Rothamsted soils. A part of the soil organic matter, when liberated from its combination with calcium and other metals, becomes readily soluble in cold, dilute alkali. The nitrogen extracted by alkali can be further fractionated by acidifying the solution ; part is precipitated and is called humic nitrogen ; part remains in solution and is called non-humic nitrogen. In the humic fraction, nitrogen occurs as protein or protein-like bodies, while the

non-humic nitrogen includes much simpler and largely soluble compounds as peptides, amino-acids and other protein decomposition products—all of which might have direct values as plant food. Nothing is known about the nature of the nitrogen in the alkali-insoluble fraction.

A number of paddy soils from different parts of India were examined according to the above scheme and the results reported in this paper. Further study on the chemical nature of the non-humic nitrogen compounds of the paddy soils, the part played by them in the nutrition of the crop, their comparison with the corresponding compounds occurring in dry cultivated soils is in progress and will form the subject matters of the future communications.

Experimental

Thirteen unmanured paddy soils, obtained from different parts of India and collected up to a depth of either 0-in.—6-in. or 0-in.—9-in. were air-dried, passed through one-mm. sieve and then submitted to alkali extraction. The methods of alkali extraction and fractionation into humic and non-humic nitrogen were briefly as follows :—

Twenty-gram portions of air-dry soil were shaken with 50 c.c. of two per cent hydrochloric acid in weighed bottles for two hours ; excess of acid was removed and the soil washed several times with distilled water. The bottles were reweighed and the amounts of residual water determined. One hundred c.c. of normal caustic soda and sufficient water to make the total volume of the liquid 200 c.c. were then added to each of the bottles which were shaken for eight hours in an end-over-end shaker. Total nitrogen was determined in an aliquot of the clear alkali extract. For the separation of the humic and non-humic nitrogen from different extracts, 50 c.c. portions of the extracts were acidified with excess of sulphuric acid and the volume made up to 250 c.c. After the precipitates had settled down, 100 c.c. of the clear liquid were taken out for the determination of total nitrogen.

Preliminary experiments carried out to observe the influence of the time of shaking on the extraction of the organic nitrogen showed that the major part of the alkali-soluble nitrogen was extracted after eight hours shaking (Table I).

Table I

Influence of time on extraction of organic nitrogen from soil

Time of shaking	N as per cent of air-dried soils	
	Soil 1	Soil 2
4 hours	0·0462	0·0380
8 „	0·0630	0·0476
16 „	0·0671	0·0490

TABLE II

Nitrogen contents of the different fractions of the organic matter (values expressed as percentage of the air-dried soils)

Soil	N extracted by direct acid treatment	Alkali-insoluble nitrogen	Humic N	Non-humic N
Karjat, Bombay	0·0012	0·0366	0·0042	0·0175
Sylhet, Assam (B)	0·0018	0·0603	0·0059	0·0420
Sylhet, Assam (C)	0·0060	0·0894	0·0161	0·0455
Rajshahi, Bengal	0·0025	0·0574	0·0112	0·0350
Insein, Burma	0·0014	0·0331	0·0035	0·0175
Coimbatore, Madras	0·0006	0·0476	0·0036	0·0245
Raipur, C. P. (Matasi)	0·0014	0·0438	0·0063	0·0315
Raipur, C. P. (Dorsa)	0·0023	0·0271	0·0014	0·0140
Faridpur, Bengal	0·0014	0·0341	0·0056	0·0210
Dacca, Bengal (E. R.)	0·0013	0·0705	0·0112	0·0420
Dacca, Bengal (N. H.)	0·0018	0·0354	0·0063	0·0385
Rangpur, Bengal	0·0041	0·0461	0·0133	0·0385
Bhagalpur, Bihar	0·0026	0·0697	0·0035	0·0175

* Acid-soluble nitrogen contains, in addition to ammonia and nitrate, little organic nitrogen.

The relative behaviour of the organic matter of the soils can be best brought out by expressing the results as percentages of the total amount of nitrogen in the soils. The results were expressed in this way in Table III.

TABLE III

Nitrogen contents of different fractions of the organic matter (N as per cent of the total soil nitrogen)

Soil	N extracted by direct acid treatment	Alkali-insoluble N	Humic N	Non-humic N
Karjat, Bombay	2	62	7	29
Sylhet, Assam (B)	2	55	5	38
Sylhet, Assam (C)	4	57	10	29
Rajshahi, Bengal	2	54	11	33
Insein, Burma	3	59	6	32
Coimbatore, Madras	1	60	8	31
Raipur, C. P. (Matasi)	2	52	8	38
Raipur, C. P. (Dorsa)	5	61	3	31
Faridpur, Bengal	2	55	9	34
Dacca, Bengal (E. R.)	1	56	9	34
Dacca, Bengal (N. H.)	2	43	8	47
Rangpur, Bengal	4	45	13	38
Bhagalpur, Bihar	3	74	4	23

The major portion of the organic nitrogen of the soils examined is insoluble in cold, dilute alkali, and of the portions soluble in alkali, eighty per cent is non-humic nitrogen. The amount of nitrogen extracted by direct acid treatment is very small, representing only three per cent of the total soil nitrogen. The very low value for humic nitrogen indicates that these soils are very poor in humus, obviously due to rapid oxidation of organic matter in soils under Indian climate. The general distribution of nitrogen in the organic matter of paddy soils is approximately as follows :—

N extracted by direct acid treatment	3 per cent
Alkali-insoluble nitrogen	56 ,,
Non-humic nitrogen	33 ,,
Humic nitrogen	8 ,,

An examination of the figures for the alkali-insoluble and the non-humic nitrogen, in Table III, will bring out a very remarkable fact. Barring the last three soils which showed some discrepancy, the proportions of the alkali-insoluble and the non-humic nitrogen in rest of the soils are nearly equal, inspite of the fact that these soils were obtained from localities, widely apart and under different climatic conditions. It is thus apparent that the organic matter of the paddy soils has acquired some uniform properties, presumably as a result of the similar treatments applied to these soils.

Extraction of nitrogen by baryta and sodium carbonate

Twenty-gram portions of soil after preliminary acid treatment, were extracted with *N*/2 barium hydroxide and *N*/5 sodium carbonate for eight hours, the procedure being identical with that described before. The results show that much less nitrogen is extracted by these solvents than by caustic soda.

Table IV

Extraction of nitrogen by baryta and sodium carbonate
(*Results are expressed as percentage of total soil-nitrogen*)

Solve	Assam soil			Rajshahi soil			Dacca soil		
	N extracted	Humic N	Non-humic N	N extracted	Humic N	Non-humic N	N extracted	Humic N	Non-humic N
N/2 NaOH . . .	39	10	29	44	11	33	43	9	34
N/2 $Ba(OH)_2$ . . .	10	1	9	6	0	6	15	1	14
N/5 Na_2Co_3 . . .	14	7	7	6	3	3	23	9	14

Rate of extraction of humic and non-humic nitrogen from soil

The manner how non-humic nitrogen compounds exist in soils is a matter of much importance. Hobson and Page [1932] suggested that these compounds

remain " incorporated in the humic-clay gel so that for the most part they go into solution only in solvents which dissolve the humic matter, and in proportion to the amount so dissolved ". In order to test this hypothesis further, and also to have some information about the manner of association between the non-humic and humic compounds of the paddy soils, two soils were extracted with alkali for varying lengths of time and the distribution of non-humic and humic nitrogen in different extracts studied. The results are as follows :—

TABLE V

Rate of extraction of humic and non-humic nitrogen from soil

(*N as per cent of total nitrogen of soil*)

	Time of extraction	Nitrogen in extract	Non-humic N	Humic N
Soil 1	1 hour	28	22	6
	3 „	33	25	8
	5 „	37	27	10
	8 „	41	29	12
	16 „	43	31	12
Soil 2	1 „	33	26	7
	3 „	34	26	8
	5 „	37	26	11
	8 „	45	33	12
	16 „	46	33	13

The results obtained with soil 1 are compatible with the suggestion of Hobson and Page. But in soil 2, the non-humic nitrogen was extracted in two instalments —nitrogen in the first instalment which came after one hour's shaking was probably linked with the humic matter, since they came into solution together. But the second instalment which was extracted after eight hours' shaking must have been associated in a different way ; for it was obtained when humic matter practically ceased to dissolve.

SUMMARY

Thirteen unmanured paddy soils from different parts of India were examined with regard to the solubility of the organic nitrogen in cold, dilute alkali and the distribution of humic and non-humic nitrogen in the alkali extracts.

It has been found that the average distribution of nitrogen in the organic matter of these soils is as follows : Nitrogen extracted by direct acid treatment—three per cent, alkali-insoluble nitrogen—fifty-six per cent, non-humic nitrogen—thirty-three per cent, humic nitrogen—eight per cent.

Caustic soda extracted much greater amount of nitrogen from the soils than baryta or sodium carbonate.

Evidence was obtained that the non-humic nitrogen compounds may occur in the soil in some manner other than being incorporated in the humic-clay gel.

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THE INHERITANCE OF SEED-CHARACTERS IN GRAM (*CICER ARIETINUM* L.)

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(With Plates LX and LXI)

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I. Introduction

The inheritance of characters in gram has been under study at the Botanical Sub-Station, Karnal, since the year 1931. The results of these investigations, dealing exclusively with the floral characters, have recently been published [Abdur Rahman Khan and Akhtar, A. R., 1934]. During the course of this work it became evident that the segregation of petal colour, reported in the previous publication, should be continued with the study of the inheritance of seed-characters.

(*1*) *Seed-colour.*—This is an important character in gram as it determines its price to a certain extent. From the market point of view, uniform yellowish brown colour fetches a higher price than dark and reddish brown. Some colours such as yellowish brown, reddish brown and dark reddish brown exhibit a certain amount of variation even among the seeds of a single plant. This variability is largely due to poor development and defective setting of seeds. Seed-colour,

again, is somewhat altered with age. Yellow or reddish colours become darker even after a few months ; brightness of colour fades and seeds appear dull. The following points have, therefore, to be borne in mind while recording observations on seed-colours :—

(1) Observations should be taken when seeds are quite fresh.

(2) Colour should be judged in mass. The colour of individual seeds always shows slight differences. Seeds can best be seen when placed in a Petri dish which facilitates noting of general colour.

(3) Shrivelled and poorly developed seeds should be left out and observations be confined to sound seeds only. In many cases improperly developed seeds look greenish and the real colour is not seen at all.

(*2*) *Seed-shape.*—This character, too, is somewhat variable. Round shape shows a good deal of variation in certain types. Seeds of type 11, for instance, which are perfectly round always have a few slightly irregular seeds. The variation is exclusively confined to seeds which are less healthy and shrivelled. The larger the number of poorly developed seeds, the greater is the proportion of slightly irregular seeds. Irregular shape is, however, much less affected by improper development. As in colour, observations should be taken only on healthy and well-developed seeds.

(*3*) *Seed-surface.*—In gram, seed-surface may be puckered, smooth, granulated or rough. These surfaces are clearly marked from one another but the intermediate grades such as slightly granulated, slightly puckered, etc., are sometimes difficult to distinguish but can be differentiated from smooth. The smooth and granulated surfaces are best distinguished under a lens. The granulated surface will show many small granulations as pustules on the seed-coat. The rough seed-coat is somewhat like sand-paper to the touch.

(*4*) *Black dots.*—When seeds of certain types are examined under a lens, it is seen that there are minute black dots on the seed-coat. In such cases, a number of seeds have to be examined very closely to detect the presence of these dots.

The above-mentioned characters have been studied in the following crosses and the results obtained are described in this paper :—

(1) T. 12 × T. 11.

(2) T. 52 × T. 11.

(3) T. 21 × T. 11.

($\times 1\frac{1}{2}$) Parent T. 12. ($\times 3$)

($\times 1\frac{1}{2}$) Parent T. 52. ($\times 3$)

($\times 1\frac{1}{2}$) ($\times 3$)

Parent T. 11.

($\times 1\frac{1}{2}$) ($\times 3$)

T. 52×T. 11. F1 Yellowish brown.

($\times 1\frac{1}{2}$) ($\times 3$)

T. 12×T. 11. F1 Reddish-brown.

Parent
T. 21.
(×1½)
(×3)
(×1½)
(×3)
Parent
T. 11.
T. 21 x T. 11.
F1
Dark-reddish-brown.
(×1½)
(×3)
F2
Dark-reddish-brown.
(×1½)
Yellowish-brown.
(×1½)
Bluish-brown.
(×1½)

II. Description of the parents.

(From Shaw, F. J. F. and Khan, A. R., 1931) and F_1

Parents and F_1	Flower colour	Seed-colour	Seed shape	Seed-surface	Presence or absence of black dots
Type 11 . .	White	Bluish brown .	Round	Smooth .	Absent
„ 12 . .	„	Reddish brown	Irregular	„ .	Absent*
„ 21 . .	Pink .	Dark reddish brown.	„	Smooth (slightly granulated).	Present
„ 52 . .	„ .	Yellowish brown	„	„	„
12×11 (F_1) .	White	Yellowish to reddish brown.	„	Smooth .	Absent
52×11 (F_1) .	Pink .	Yellowish brown	„	As in T. 52 .	Present
21×11 (F_1) .	„ .	Dark reddish brown lighter than T. 21.	„	As in T. 21 .	„

The seed-characters of the parents and F_1 are illustrated in Plates LX and LXI.

* A very few faint dots are sometimes present on seeds of T. 12 but as they are hardly visible to the naked eye they have been treated as absent.

III. Results of the F_2 generations

Cross No. 1 (T. 12×T. 11)

The following segregation was observed in the F_2 :—

Phenotypes	Frequencies		Deviation	Probable error
	Observed	Expected on 3 : 1 ratio		
Seed, yellowish to reddish brown, irregular as in T. 12.	22	22·5	0·5	1·59
Seed, bluish brown, round as in T. 11 .	8	7·5	0·5	
Total .	30			

The fit is good.

Considering the segregation, character by character, it is evident that reddish brown colour and irregular shape are dominant over bluish brown colour and round shape respectively and each case shows a unit factor difference.

Association of characters.—It has been observed in this cross that the reddish brown colour and irregular shape, and similarly bluish brown colour and round shape, go together. This shows that these characters are probably linked together and the F_3 results, as will be seen later lend support to this assumption.

Cross No. 2 (T. 52 × T. 11)

Segregations in the F_2 :—

Phenotypes	Frequencies		Deviation	Probable error
	Observed	Expected on 3 : 1 ratio		
Seed, yellowish brown, irregular, slightly granulated as in T. 52.	39	41·25	2·25	2·16
Seed, bluish brown, round and smooth as in T. 11.	16	13·75	2·25	
Total .	55			

The fit is good.

Presence of black dots, on seed-coat in F_2

Phenotypes	Frequencies		Deviation	Probable error
	Observed	Expected on 15 : 1 ratio		
Black dots present	51	51·56	0·56	1·24
„ „ absent	4	3·44		
Total .	55			

The fit is good.

It is evident from the above results that yellowish brown colour, irregular shape, slightly granulated surface and presence of black dots are dominant over bluish brown colour, round shape, smooth surface and absence of black dots respectively. Each one of these characters, excepting the presence of black dots which seems to be determined by two factors, shows a single factor difference.

In the F_2, the following results were obtained with respect to flower-colour and seed-colour :—

Flower-colour	Pink	Blue	White	
Seed-colour	Yellowish brown.	Bluish brown	Yellowish brown.	Bluish brown
Seed-shape	Irregular	Round	Irregular	Round
Seed-surface	Slightly granulated.	Smooth	Slightly granulated.	Smooth
Black dots	Present prominently.	Present faintly.	Present faintly.	Absent
Observed frequencies	31	12	8	4
Expected on 9 : 3 : 3 :1 ratio.	30·94	10·31	10·31	3·44

$\chi^2 = 0{\cdot}8857$, when $\chi^2 = 1$, $P = 0{\cdot}801253$. The fit is excellent.

This table also explains the segregation of black dots on the basis of 15 : 1 ratio as mentioned before. The black dots are many and prominent when the flower is pink. They are few and faint when the flower is blue and seed bluish brown in colour or when flower is white and seeds are yellowish brown. This appears to be due to the cumulative effect of two factors—each one producing faint dots. These faint dots are practically absent when seeds have a reddish or greenish tinge and in such cases only a dot or two is revealed by a close examination under a lens. When, however, seeds are badly developed and shrivelled the dots are not seen at all. This may be due to imperfect development of the seeds.

Cross No. III (T. 21 × T. 11)

In the F_2 generation the following segregation was observed :—

(1) Seed-colour

Phenotypes	Frequencies		(O—C)	$\frac{(O-C)^2}{C}$
	Observed	Expected on 9 : 3 : 4 ratio		
Dark reddish brown	33	29·81	3·19	0·34
Yellowish brown	10	9·94	0·06	0·0005
Bluish brown	10	13·25	3·25	0·79
Total	53	..	$\chi^2 = 1{\cdot}13$ $P = 0{\cdot}573$	

The fit is good.

(2) *Seed-shape and —surface*

Phenotypes	Frequencies		Dev.	P. E.
	Observed	Expected on 3 : 1 ratio		
Irregular and slightly granulated .	43	39·75	3·25	2·12
Round and smooth	10	13·25		
Total .	53	..	..	..

The fit is good.

(3) *Black dots*

Phenotypes	Frequencies		Dev.	P. E.
	Observed	Expected on 15 : 1 ratio		
Black dots present	50	49·69	0·69	1·15
Black dots absent	3	3·31		
Total .	53	..	..	..

The fit is good.

Association of seed-characters

The following table illustrates this :—

Seed-colour	Shape	Surface	Black dots	Obs.
Dark reddish brown . .	Irregular .	Slightly granulated.	Present .	33
Yellowish brown . . .	Do. .	Do. .	Do. .	10
Bluish brown . . .	Round .	Smooth .	Present .	7
			Absent .	3

Seed-characters in relation to flower-colours

As seen in cross No. II seed colour, etc., show a definite relation with flower-colour as is evident from the following table :—

Table showing the relation of flower-colour with the seed-characters

Flower-colour	Seed-colour	Seed-shape	seed-surface	Black dots	Obs.
Pink . .	Dark reddish brown.	Irregular	Slightly granulated.	Present prominently.	20
,, . .	Yellowish brown	,, .	,, .	,, .	7
White . .	Dark reddish brown.	,, .	,, .	Present faintly.	13
,, . .	Yellowish Brown	,, .	,, .	,, .	3
,, . .	Bluish brown .	Round .	Smooth .	Absent .	3
Blue . .	,, .	,, .	,, .	Present faintly.	7
				Total .	53

The inheritance of black dots on seed appears to be the same as observed in cross II.

IV. Theory and discussions of the results with reference to the F_3 generation

A=a factor for bluish brown seed-colour, round shape, smooth surface. It has no action on flower-colour.

R=a factor that modifies the action of **A** turning bluish brown colour to reddish brown and round to irregular seed.

B=a factor which operates in the same way as **A** but in addition produces blue flower and faint black dots on seeds.

P=a factor that modifies the action of **B** turning blue flower to pink. It reacts with **A** as well as with **B**, converting bluish brown seeds to yellowish brown, round to irregular and smooth to slightly granulated. It produces faint black dots on seed when present alone, but reacts with **B** to intensify black dots on the seed-coat.

D=a factor that modifies the action of **P** turning yellowish brown seed-colour to dark reddish brown.

On the assumption of the above theory, the constitutions of the parental types are as given below :—

T. 11 = **AArrbbppdd**
T. 12 = **AARRbbppdd**
T. 52 = **AArrBBPPdd**
T. 21 = **AArrBBPPDD**

NOTE.—By supposing that the flower-colour, factor **P** produces yellowish brown seed- colour independently it is not necessary to have factor **A** in the constitution of the types. But the factor **P** has been found to be present in T. 1, T. 2 and T. 9 [Khan and Akhtar, 1934] and the seed-colour of these types is white with reddish tinge and not yellowish brown. Factor **P** has, therefore, been supposed to modify bluish brown colour that is produced by factor **A**.

Cross I (T. 12 × T. 11)

In this cross the factor **R** segregates and on recombination gives a mono-hybrid ratio as realised in the F_2 generation.

The results of the F_3 generation, as will be seen below, have confirmed the above theory. Sixteen cultures were grown in the F_3 generation and these behaved as follows :—

Number and nature of F_2 parent	Behaviour in F_3 generation	Constitution of F_2 genotype	Frequencies	
			Observed	Expected
11 Reddish brown irregular	Pure	AARR	5	3·66
	Segregating like F_2	AARr	6	7·34
5 Bluish brown round	Pure	AArr	5	5·00

The six splitting cultures showed the following segregation :—

F_3 cultures number	Reddish brown irregular	Bluish brown round	Total
1—41	28	10	38
1—42	28	5	33
3—44	27	10	37
3—48	28	12	40
4—41	28	9	37
3—47	28	10	38
Total observed	167	56	223
Expected on 3 : 1 ratio	167·25	55·75	..
Deviation	0·25	0·25	..

The fit is good.

During the course of observations some F_3 cultures showed a certain amount of variation from the parental seed-colour. The seed-colour was found to vary from deep reddish brown to light reddish brown. On breeding a few F_3 plants from each of the extreme classes, the F_4 progenies showed uniformity as regards seed-colour, thereby indicating that the apparent variations in F_3 were but fluctuations due to environments.

Cross II (T. 52 × T. 11)

The constitutions of the parents and F_1 :—

Parent type 52 = **AABBPPrr**
" 11 = **AAbbpprr**
F_1 = **AABbPprr**

The factors **B** and **P** alone segregate and give the following results in F_2 generation.

	9 ABP	3 ABp	3 AbP	1 Abp
Flower-colour	Pink	Blue	White	White
Seed-colour	Yellowish brown.	Bluish brown	Yellowish brown.	Bluish brown
Seed-shape	Irregular	Round	Irregular	Round
Seed-surface	Slightly granulated.	Smooth	Slightly granulated.	Smooth
Black dots	Present prominently.	Present lightly.	Present lightly.	Absent

The results obtained in the F_2 generation are in perfect agreement with this theory (page 1091) and were subsequently confirmed in F_3 as shown below.

Twenty-nine F_2 plants representing the various phenotypes were grown in F_3 generation and their behaviour with regard to seed-characters is given in the following table :—

No. and nature of F_2 plants	Behaviour in F_3	Constitution of F_2 genotypes	Frequencies	
			Observed	Expected
23 Yellowish brown irregular, slightly granulated.	Pure	AABBPP, AABbPP, AAbbPP	11	7·7
	3 yel. br. : 1 blu. br.	AABBPp, AAbbPp, AABbPp	12	15·3
6 Bluish brown, round smooth.	Pure	AABBpp, AABbpp, AAbbpp	6	6

The segregation of the twelve splitting cultures is as follows :—

F_3 cultures number	Seeds yellowish brown, irregular, slightly granulated	Seeds bluish brown, round, smooth	Total
4—34	21	9	30
4—37	15	16	31
4—40	17	12	29
3—2	28	9	37
3—27	25	6	31
3—24	25	11	36
4—15	24	12	36
4—39	14	11	25
3—9	14	5	19
3—32	25	13	38
3—33	29	9	38
4—14	26	12	38
Total observed . . .	263	125	388
Expected	291	97	..
Deviation	28	28	..
	Probable error . .	5·73	

The fit is bad.

On examining the segregation of individual F_2 plants, given in the above table, it will be seen that this discrepancy is mainly confined to three F_3 cultures, *viz.*, 4—37, 4—39 and 4—40, while all the rest give a fairly good fit. Again it must be mentioned that some plants having pink flowers and evidently yellowish brown seeds, had to be rejected as the seeds from these were poorly developed and shrivelled. If these are added the deviation is reduced.

The behaviour of F_3 cultures in seed-colour is better understood when considered with flower-colour. This is shown below :—

The behaviour of F_3 cultures in relation to seed-colour and flower-colour

Number and nature of parents	Behaviour in F_3			Constitution of F_2 genotypes	Frequencies		Group
	Flower-colour	Seed-colour	Black dots on seed coat		Observed	Expected	
18 .	Pure pink .	Pure yellowish brown	Pure for prominent dots	**AABBPP** .	2	2	I
Flower pink and seed yellowish brown, etc.	3 pink : 1 white .	Do. .	3 Prom. : 1 Faint .	**AABbPP** .	8	4	II
	3 pink : 1 blue .	3 yell. br. : 1 blu. br.	3 Prom. : 1 Faint .	**AABBPp** .	3	4	III
	9 pink : 3 blue : 4 white.	12 yell. br. : 4 blu. br.	Like F_2 . .	**AABbPp** .	5	8	IV
5							
Flower white and seed yellowish brown, etc.	Pure white .	Pure yell. br. .	Pure for faint dots	**AAbbPP** .	1	1·7	V
	Do. . .	3 yell. br. : 1 blu. br.	3 Faint : 1 no dots .	**AAbbPp**	4	3·3	VI
2							
Flower white and seed bluish brown, etc.	Pure white .	Pure bluish brown .	Pure for no dots .	**AAbbpp** .	2	2	VII
	Do. .	Do. .	Do. .				
4							
Flower blue and seed bluish brown, etc.	Pure blue . .	Pure bluish br. .	Pure for faint dots .	**AABBpp** .	0	1·3	VIII
	3 Blue : 1 white .	Do. .	3 Faint : 1 no dots .	**AABbpp** .	4	2·7	IX

The segregation in the 8 F_3 cultures of group II was :—

	Flower pink (black dots on seed prominent)	White (black dots on seed faint)	Total
Total observed . . .	208	74	282
Expected on 3 : 1 ratio . .	211·5	70·5	(P. E. =4·90)

The fit is good.

Segregations in group III :—

Culture No.	Flower pink, seed yellowish brown, black dots prominent	Blue, bluish brown, etc., black dots faint	Total
4—34	21	9	30
4—37	15	16	31
4—40	17	12	29
Total observed . . .	53	37	90
Expected on 3 : 1 ratio . .	67·5	22·5	..
Deviation	15·5	P. E. =2·76	

The fit is not good due to discrepancy in cultures 4—37 and 4—40 owing to deficiency in pink flowered plants as explained before (page 1096).

Segregation in group IV :—

Culture No.	Flower pink		Flower white	Flower blue
	Seed yellowish brown, etc., dots present	Yellowish brown, etc., dots present	Bluish brown dots absent	Bluish brown, etc., dots present
3—2 . . .	19	9	2	7
3—27 . . .	19	6	2	4
3—24 . . .	19	6	0	11
4—15 . . .	18	6	4	8
4—39 . . .	11	3	2	9
Total observed .	86	30	10	39
	116		49	=165
Expected on 9 : 3 : 1 : 3 ratio.	92·82	30·93	10·31	30·93
	123·75		41·25 (P.E. 3·37)	

$P = 0·4422$, $\chi^2 = 2·72$.

Considering dots independently we get :—

	Dots present	Dots absent
Total observed	155	10
Expected on 15 : 1 ratio	154·59	10·31

The fit is good.

There is an excess in blue flowered plants and deficiency in pink. This may be due to the rejection of some pink flowered plants that had poorly developed seeds and so could not be taken into account in the classification of seed-colour and also to the small population in the different cultures.

Segregation in group VI (white flowered).

Culture No.	Yellowish brown, irregular, etc., black dots faint	Bluish brown, round, etc., black dots absent
3—9	14	5
3—32	25	13
3—33	29	9
4—14	26	12
Total observed	94	39
Expected on 3 : 1 ratio	99·75	33·25
Probable error	3·27	

Similarly in group IX no black dots could be seen on the bluish brown seeds having white flowers.

Cross III (T. 21 × T. 11)

Parent Type 21 = **AABBPPDD**

Parent Type 11 = **AAbbppdd**

In the F_2 generation factors **B**, **P** and **D** segregate and give the following results :—

——	Flower colour	Seed colour	Frequency	
			Observed	Expected
27—**ABPD**	Pink	Dark reddish brown	20	22·41
9—**ABPd**	,,	Yellowish brown	7	7·47
9—**AbPD**	White	Dark reddish brown	13	7·47
9—**ABpD**	Blue	Bluish brown	7	9·96
3—**ABpd**	,,	,, ,,		
3—**AbPd**	White	Yellowish brown	3	2·49
3—**AbpD**	,,	Bluish brown	3	3·32
1—**Abpd**	,,	,, ,,		
Total	..	..	53	..

The expected frequency is based on the ratio of 27 : 9 : 9 : 12 : 3 : 4.

From the above table we get the following segregation in F_2 :—

1. Seed-colour

Phenotypes	Seed-colour	Frequencies	
		Observed	Expected on 36 : 12 : 16 ratio
27—ABPD	Dark reddish brown	33	29·81
9—AbPD	,, ,, ,,		
9—ABPd	Yellowish brown .	10	9·94
3—AbPd	,, ,, .		
9—ABpD	Bluish brown .	10	13·25
3—ABpd	,, ,, .		
3—AbpD	,, ,, .		
1—Abpd	,, ,, .		

The fit is good as mentioned before (page 1091).

2. Seed-shape, surface, and presence of black dots being linked with seed-colour will all behave similarly as shown below :—

Phenotypes	Seed-colour	Shape, surface black dots	Frequencies	
			Obs.	Expected on 48 : 16 ratio
27—ABPD . . .	Dark reddish	Irregular, slightly		
9—AbPD.	brown.	granulated.	43	39·75
9—ABPd . . .	Yellowish	Having black dots .		
3—AbPd.	brown.			
9—ABpD . . .	Bluish brown	Round, smooth having black dots.	7	
3—ABpd . . .			10	13·25
3—AbpD . . .		Round, smooth	3	
1—Abpd . . .		black dots absent.		
		Total .	53	..

F_3 results

Twenty-eight cultures were grown in F_3. Their behaviour with regard to seed-characters is given below :—

Number and nature of F_2 parents	Behaviour in F_3	Constitution of F_3 genotype	Frequencies	
			Observed	Expected
16 Seed dark brown, irregular, etc.	Pure dark brown irregular, etc.	**AABBDDPP** **AABbDDPP** **AAbbDDPP**	3	1·77
	3 dark brown, to 1 yellow brown (irregular, etc.).	**AABBDdPP** **AABbDdPP** **AAbbDdPP**	6	3·55
	3 dark brown, irregular, etc. 1 bluish brown, round, etc.	**AABBDDPp** **AABbDDPp** **AAbbDDPp**	3	3·55
	9 dark brown, irregular, etc. 3 yellowish brown, irregular, etc. 4 bluish brown, round, etc.	**AABBDdPp** **AABbDdPp** **AAbbDdPp**	4	7·11
5 Seed yellowish brown, irregular, etc.	Pure yellow brown, irregular, etc.	**AABBddPP** **AABbddPP** **AAbbddPP**	1	1·66
	3 yellow brown, irregular, etc. 1 bluish brown, round, etc.	**AABBddPp** **AABbddPp** **AAbbddPp**	4	3·33
7 Seed bluish brown, round, etc.	Pure bluish, brown, round, etc.	**AABBDDpp** **AABbDDpp** **AABBDdpp** **AABbDdpp** **AABBddpp** **AABbddpp** **AAbbDDpp** **AAbbDdpp** **AAbbddpp**	7	7

The details of F_3 behaviour tabulated above are given hereunder.

Sixteen cultures from dark reddish brown, irregular, slightly granulated seed with black dots were grown in F_3. Out of these three bred true and six segregated into dark reddish brown and yellowish brown seeds as follows :—

——	Dark reddish brown	Yellowish brown	Total
Observed	152	52	204
Expected 3 : 1 . . .	153	51	..

Three cultures segregated into dark reddish brown to bluish brown seeds as follows :—

——	Dark reddish brown	Bluish brown	Total
Total observed . . .	52	20	72
Expected 3 : 1 . . .	54	18	..

The remaining four cultures segregated like F_2 and gave the following results :—

——	Dark reddish brown	Yellowish brown	Bluish brown	Total
Total observed . . .	75	21	33	129
Expected 36 : 12 : 16 (9 : 3 : 4)	72·56	24·19	32·25	..

Out of the five cultures having yellowish brown, irregular, slightly granulated seeds with black dots, one culture bred true. The remaining four segregated as follows :—

——	Yellowish brown	Bluish brown	Total
Total observed . . .	84	28	112
Expected on 3 : 1 . .	84	28	..

All the seven cultures having bluish brown, round, smooth and very small seeds (one without black dots and six having black dots), bred true as per expectation.

F_3 behaviour of flower and seed colours

Number and nature of F_2 parent	Behaviour in F_3		Constitution of F_2 genotypes	Frequencies	
	Flower-colour	Seed-colour		Observed	Expected
12 Flower—pink. Seeds—dark brown.	Pure pink 3 pink : 1 white Pure pink 3 pink : 1 white Do. 9 pink : 3 blue : 4 white Do. 3 pink : 1 blue 3 pink : 1 white	Pure dark brown Do. 3 dr. br. : 1 yel. br. Do. 3 dr. br. : 1 blu. br. Do. 9 dr. br. : 3 yel. br. : 4 blu. br. Do. Do.	**AABBDDPP**. **AABbDDPP**. **AABBDdPP**. **AABbDdPP**. **AABBDDPp** **AABbDDPp**. **AABbDdPp**. **AABBDdPp**. **AAbbDdPp**.	0 2 1 3 0 2 1 2 1	0·44 0·88 0·44 1·76 0·88 1·76 1·76 3·52 1·76
4 Flower—white. Seed—dark brown.	Pure white Do. Do.	Pure dark brown 3 dr. br. : 1 yel. br. 3 dr. br. : 1 blu. br.	**AAbbDDPP**. **AAbbDdPP**. **AAbbDDPp**.	1 2 1	0·44 0·88 0·88
4 Flower—pink. Seed—yellowish brown.	Pure pink 3 pink : 1 white 3 pink : 1 blue 9 pink : 3 blue : 4 white	Pure yellowish brown Do. 3 yel. br. : 1 blu. br. Do.	**AABBddPP**. **AABbddPP**. **AABBddPp**. **AABbddPp**.	0 1 2 1	0·44 0·88 0·88 1·76
1 Flower—white. Seed—yellowish brown.	Pure white Do.	Pure yellowish brown 3 yel. br. : 1 blu. br.	**AAbbddPP**. **AAbbddPp**.	0 1	0.44 0.88
1 Flower—white. Seed—bluish brown.	Pure white Do.	Pure bluish brown	**AAbbDDpp**. **AAbbDdpp**. **AAbbddpp**.	1	1·76
6 Flower—white. Seed—bluish brown.	Pure blue Do. 3 blue : 1 white	Pure bluish brown .... Do.	**AABBDDpp**. **AABBDdpp**. **AABBddpp**. **AABbDDpp**. **AABbDdpp**. **AABbddpp**.	1 3	1·76 3·42

It is evident from these results that the seed-characters and flower-colour are perfectly linked as observed in F_2 generation.

The behaviour of black dots in the F_3 generation of this cross was similar to that described in Cross II (T. 52 × T. 11) and so has not been repeated.

NOTE :—Large populations of all the crosses were grown in the F_2 generation and F_3 cultures but unfortunately the gram plants were damaged much by *Rhizoctonia* at Karnal and so extensive observations could not be recorded.

The seed-size was studied by eye judgment in all the crosses. The seeds of T. 11 may be called as very small and those of other types as comparatively larger. Very small size went together with bluish brown seeds as in T. 11 and larger seeds went with the seed-colour of other types. The results regarding seed-size have not been presented because the populations of the crosses were not big enough to ascertain definitely whether the seed-size which is expected to be a quantitative character is really behaving as mentioned above.

The authors desire to acknowledge the help rendered by Mr. Habibur Rahman Khan, Fieldman, during the course of these investigations.

V. SUMMARY

The inheritance of colour, shape and surface of seed, has been studied in the three crosses between Pusa gram types 11, 12, 52 and 21. The results of segregations have been given and discussed. The following facts have been noted :—

(1) The bluish brown seed-colour as in type 11 is dependent on a single factor **A** or **B**.

(2) The reddish brown seed-colour of type 12 is produced by the interaction of factors **A** and **R**.

(3) The factor **P** modifies the action of **A** or **B** turning bluish brown seed-colour to yellowish brown as in type 52.

(4) The dark reddish brown colour of seed as in type 21 is determined by the interaction of the factors **A**, **P** and **D** or **B**, **P** and **D**.

(5) In all the three crosses, the bluish brown seed-colour of the common parent, type 11, behaves as a recessive to reddish brown, yellowish brown and dark reddish brown seed-colours of types 12, 52 and 21 respectively.

It is shown that the colour, shape and surface of seed are all associated.

Group I.—The yellowish brown and dark reddish brown colours are linked with irregular shape and slightly granulated surface.

Group II.—The bluish brown colour is linked with round shape and smooth surface.

Besides the above associations it is clear that the flower-colour is also linked with these seed-characters—pink flower is associated with group I with prominent black dots, and blue flower with group II having faint black dots.

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S. spontaneum (Dehra Dun) × *Sorghum Durra*.

A PRELIMINARY NOTE ON A NEW SACCHARUM × SORGHUM HYBRID

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(With plates LXII and LXIII)

In sugarcane-breeding it has been the custom to use as female parents canes that are pollen-sterile. Such plants are also generally complex hybrids. Thus in the successful intergeneric hybrids evolved at Coimbatore [Venkatraman and Thomas, 1930] the female parent used, P. O. J. 2725, was a noble cane from Java with a complex heredity. It has further about 106 chromosomes.

With a view to understanding the genetic relationship between the genus *Saccharum* and *Sorghum*, a number of crosses were made in 1934-1935 in which the female parents were simpler forms of *Saccharum*. Amongst such parents employed was the wild species, *Saccharum spontaneum* L. which is being increasingly used in Coimbatore for the breeding of disease and drought-resisting sugarcanes. A number of chromosomal forms are found in this species [Janaki Ammal, 1936] and the hybrid reported is a cross between a form from Dehra Dun ($2n=56$) and *Sorghum durra* (*Periamanjal* of Coimbatore), the same parent used in the intergeneric cross P. O. J. 2725×*Sorghum*. In *Sorghum durra* the chromosome number $2n=20$.

As the *S. spontaneum* used was nearly 100 per cent pollen-fertile, pollination with *Sorghum* was effected after emasculation of spikelets. The arrows were bagged after dusting with *Sorghum* pollen. Thirteen seedlings were produced, all of which are now in field. In appearance they resemble *S. spontaneum* more than *Sorghum* (Plate LXII). The plants arrowed five months after germination, *i.e.* four months before the usual time of flowering in *Saccharum*. This early flowering habit is apparently inherited from *Sorghum*. It was however found to be completely pollen-sterile.

Plate LXIII shows the nature of the spikelet of the parents and hybrid.

S. spontaneum differs from *S. officinarum* in having a rudimentary IV glume. This IV glume, which is also present in *Sorghum*, is awned in this genus. The presence of this awned IV glume in the hybrid as well as the callus hairs inherited from *Saccharum* makes the validity of this new intergeneric cross unquestionable. The number of chromosomes in root tip of the hybrid is thirty-eight which is the sum of the haploid numbers of the Dehra Dun *S. spontaneum* and *Sorghum*. A more detailed study of its cytology will appear elsewhere.

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1. Spikelets of the intergeneric hybrid S. *spontaneum* (Dehra Dun) × *Sorghum Durra*.

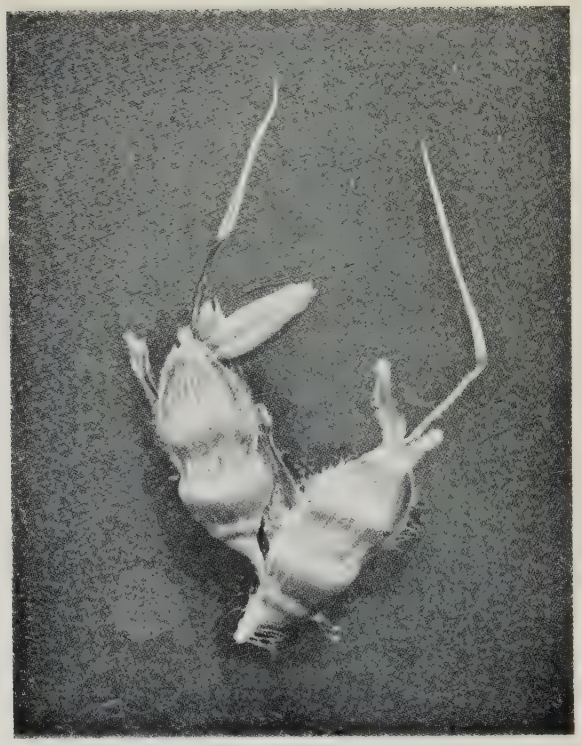

FIG. 2. Spikelets of *Sorghum Durra*.

FIG. 3. Spikelets of *S. spontaneum* (Dehra Dun).

STATISTICAL NOTES FOR AGRICULTURAL WORKERS

NO. 19.—THE FREQUENCY DISTRIBUTION OF PLOT YIELDS AND THE OPTIMUM SIZE OF PLOTS IN A UNIFORMITY TRIAL WITH RICE IN ASSAM

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(With three text-figures.)

INTRODUCTION

The tests of significance used in the analysis of the results of agricultural field trials are based on the assumption that yields from individual plots conform to the normal distribution or at least do not deviate so far from normality as to render such tests invalid. Very little is known at present regarding the real nature of the frequency distribution of plot yields of agricultural crops in India. It is desirable therefore to study this question for all important crops under different conditions of cultivation in the different provinces of India. This is the first point considered in the present note.

The effect of the size and shape of plots on the magnitude of the experimental error in field trials also requires careful study. It is possible that there is no single optimum for all purposes. In fact, previous work has shown the wide range of variation under different conditions.

The potato experiment at Ormskirk [1932] showed 195 ft. × 8 ft. (=1/28 acre approximately) to be the best plot size, with an experimental error of 4·9 per cent. Another potato experiment (1932) at Saskatchewan showed this optimum size to be 132 ft. × 15 ft. 9 in.(=1/21 acre) with an experimental error of 5·1 per cent. In both these experiments, the smallest plot size was found to be the most efficient. Workers on Sorghum in Texas obtained 1/40 to 1/80 acre to be the most suitable. With regard to sugarcane tests the work done at Pusa [Vaidyanathan, 1933] indicated the optimum size to be between 1/20 and 1/30 acre—the ratio of length to breadth being 6·7 to 10·1. Several rice tests have been reported in different parts of India and Ceylon. Lord [1931] working with broadcast rice in Anuradhapura (Ceylon) obtained 1/87 acre to be the most convenient size for practical purposes. Mitra and Ganguli [1934] working

in Assam found 60 ft.×10 ft. (=1/72·6 acre) to be the best for *Aman*, and 60 ft. ×15 ft. (=1/48·4 acre) for *Aus*. In China a recent article by Chien Liang Pan [1935] indicates the optimum size to be 14·2 ft.×3·0 ft. (=1/1025 acre) at Hangchow Central Station, and 14·2 ft.×1·5 ft. (=1/2050 acre) at Wufu.

It is thus clear that the optimum size and shape of plots depends to a very great extent on the crop, the nature of the soil, and the conditions of cultivation. It is, therefore, necessary and desirable to conduct detailed and careful analysis of the results of uniformity trials until sufficient experience has been gathered in this matter. This is the second question studied in this paper.

Material and method

The material for the present study was obtained from an experiment conducted in Karimganj Farm in Assam in 1933. Two 1/10 acre plots measuring 66 ft. × 66 ft. were grown with *As. 2 Kasalath*, a transplanted paddy of *Aus* type. Single seedlings were planted six inches apart. Each field was harvested in the form of a Latin Square with twelve rows and twelve columns with individual plots measuring 5 ft.×5 ft. and containing 100 plants each. Five rows were left out from all sides round the experimental area to eliminate border effects if any; but it was not necessary to eliminate any row round the small plots (5 ft.×5 ft.) as the whole field was uniformly cropped without any special *ails* or spacing anywhere. There were 2×144 or 288 plots in all, and these were harvested, threshed, dried and weighed (in *tolas**) separately.

Frequency distribution of yield data

The data for the two fields were studied separately as well as in combination. The frequency distributions of two sets of 144 observations as well as their combination are shown in Tables I—III.

Table I

Observed and expected frequency distributions of plot-yields of rice (Field I)

Range	Observed (f')	Expected (f)	$(f-f')^2/f$
Below 39·5	1·5	1·74	0·0331
41·0	6	3·28	2·2556
42·5	5·5	7·24	0·4182
44·0	12	13·13	0·0973
45·5	19	19·68	0·0235
47·0	24	24·34	0·0047
48·5	23	24·85	0·1377
50·0	27·5	20·85	2·1210
51·5	12	14·49	0·4279
53·0	8	8·28	0·0095
54·5	1·5	3·92	1·4940
54·5 and beyond	4	2·20	1·4727
Total	144·0	144·00	$\chi^2=8·4952$

* 1 *tola*=11·6638 grammes=0·4114 ozs.

Table II

Observed and expected frequency distributions of plot-yields of rice (Field II)

Range	Observed (f′)	Expected (f)	$(f-f')^2/f$
Below 38·0	1 } 3·5	1·05 } 3·24	
39·5	0	0·56	0·0209
41·0	2·5	1·63	
42·5	5	3·95	0·2791
44·0	6	8·04	0·5176
45·5	13	13·68	0·0338
47·0	18	19·61	0·1322
48·5	25	23·46	0·1011
50·0	19·5	23·67	0·7346
51·5	22	19·92	0·2172
53·0	20	14·14	2·4285
54·5	6	8·37	0·6711
56·0	5	4·18	0·1609
56·0 and beyond	1	1·74	0·3147
Total	144·0	144·00	$\chi^2=5·6117$

Table III

Observed and expected frequency distributions of plot-yield of rice (Fields I and II combined)

Range	Observed (f′)	Expected (f)	$(f-f')^2/f$
Below 38·0	1 } 2·5	1·71 } 3·58	
39·5	1·5	1·87	0·3258
41·0	8·5	5·01	2·4312
42·5	10·5	11·17	0·0402
44·0	18	21·05	0·4419
45·5	32	33·09	0·0359
47·0	42	43·72	0·0677
48·5	48	48·21	0·0009
50·0	47	44·67	0·1215
51·5	34	34·79	0·0179
53·0	28	22·58	1·3010
54·5	7·5	12·33	1·8920
56·0	9	5·64	2·0017
56·0 and beyond	1	2·16	0·6230
Total	288·0	288·00	$\chi^2=9·3007$

The frequency constants are shown in Table IV.

TABLE IV

Frequency constants for plot-yields of rice with Standard Errors

	Field I	Field II	Total area
Size of sample . .	144	144	288
Mean . . .	47·1510±0·2827	48·5521±0·2959	47·8515±0·2088
Standard Deviation .	3·3922±0·3998	3·5505±0·4185	3·5424±0·2952
μ_2	11·5085±0·9147	12·6068±1·0021	12·5483±0·9975
μ_3	—1·9838±5·3742	—14·8723±6·1622	—7·2741±6·1203
μ_4	384·2038±62·3655	472·4821±87·5178	446·0285±86·7243
β_1	0·0026±0·0035	0·1104±0·1200	0·0268±0·0247
β_2	2·9009±0·3536	2·9729±0·4639	2·8327±0·2478

It will be seen from Table IV that mean yield in Field II was slightly higher than that of Field I, although the difference was only 1.4011 tolas per plot. The standard deviations of the two fields were also not very different, the ratio of the standard deviations is 1·047, and for $n_1=n_2=143$ is not significant.

The third moment is negligible in Field I, but it is appreciably negative in Field II. The symmetrical form of the distribution in Fig. 1, and the skew curve with a bias on the higher yield side in Fig. 2 show the same results graphically. Fig. 3 shows the frequency distribution of the entire set of results.

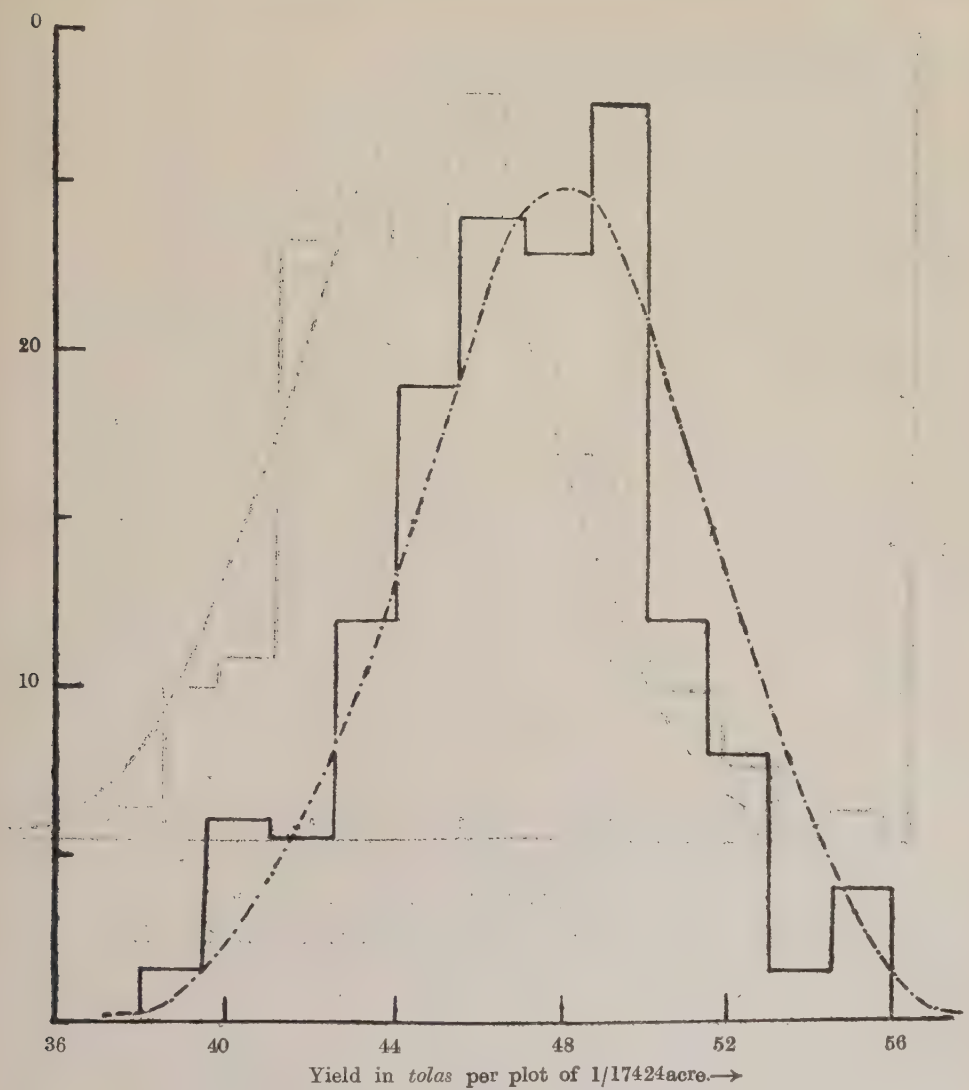

Fig. 1. Frequency distribution of yields of rice in field I.

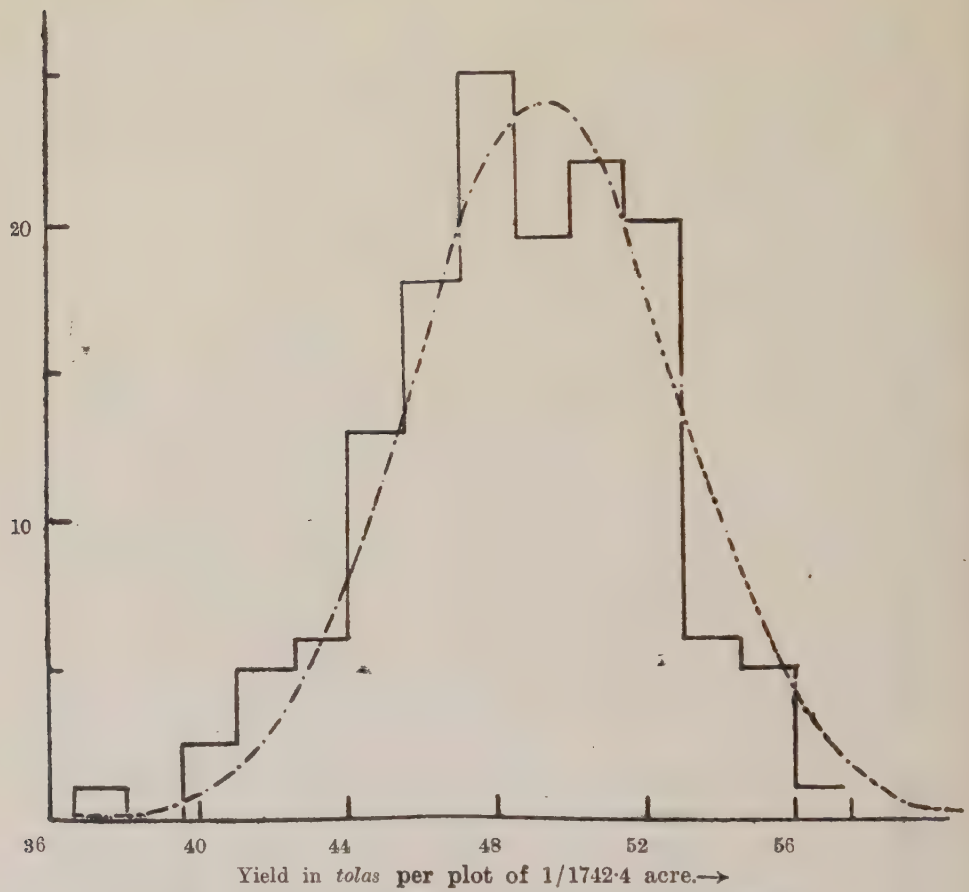

Fig. 2. Frequency distribution of yield of rice in field II.

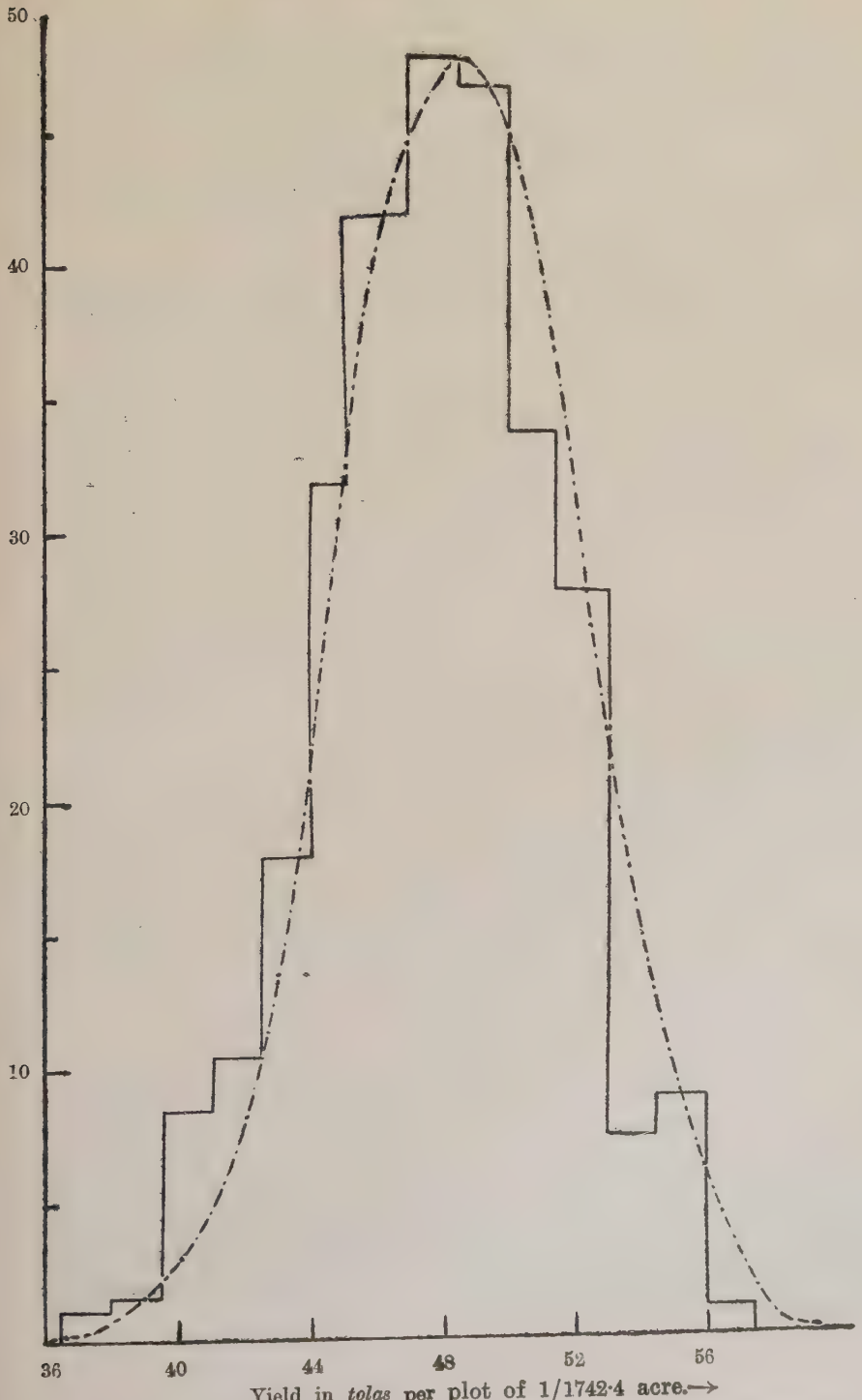

Fig. 3. Frequency distribution of yield of rice in fields I and II.

The standard errors of β_1 and β_2 are large, as the sample is too small to give reliable estimates of third and higher moments. Judged in the light of respective standard errors, the β_1 values are not significantly different from zero, and the β_2 values are also not significantly different from 3, the expected value for the normal curve. The distribution of rice-yields may thus, as far as the fourth moment, be considered to be a sample from a normal population. The observed distributions have been, therefore, graduated by a normal curve, with mean and variance obtained from the sample.

The expected values for each of the frequency distributions (separately, and in combination) have been shown in column (3) and χ^2 values in column (4) in Tables I—III.

TABLE V

Test of goodness of fit by a normal curve

	n	χ^2	P
Field I . . .	9	8·4952	0·48
Field II . . .	9	5·6113	0·78
Total area .	10	9 1307	0·52

The data for testing the goodness of fit are given in Table 5, in which column (2) shows the degrees of freedom on which χ^2 has been calculated, and P (in column 4) gives the corresponding probability of occurrence of systems of deviations as great or greater than the observed system.

We thus find that if our plot yield data are considered to be a sample from a normal population, the chances are 48 in 100 in Field I that χ^2 should be as big as or bigger than the observed value; that is, the fit of a sample from a strictly normal population would be as bad as or worse in forty-eight per cent of cases. Hence, the hypothesis that the yield data conform to a normal distribution may be accepted as true for all practical purposes. In the same way the assumption of a normal distribution for the uniformity trial data is statistically justified for field II, as well as for the combined experiment.

Standard Deviation of plots of different shape and size

The lay-out of the experiment was in the form of two Latin Squares with twelve rows and twelve columns each. It was thus possible to conduct the analysis for plots of twenty-five different sizes and shapes, the smallest being 5 ft. × 5 ft. and the largest 30 ft. × 30 ft. In each case, the effect of soil heterogeneity was eliminated by subtracting the sums of squares between rows and columns within each Latin Square from the total sum of squares, and the variation between the two Latin Squares was also allowed for. The analysis of variance for the 5 ft. × 5 ft. plot is shown in Table VI.

TABLE VI

Analysis of variance of rice yield

(Plot-size 5 ft. × 5 ft.)

	D F.	Sum of squares	Mean Square	Ratio of variance
Field	1	131·0176	131·0176	14·24
Row	22	658·7119	29·9414	3·25
Column	22	566·3368	25·7425	2·80
Soil-difference	45	1356·0663	30·1348	3·27
Residual	242	2227·1656	9·2031	..
Total	287	3583·2319	12·4851	

The mean yield of plot of this size (5 ft. × 5 ft.) is 47·85, so that the residual standard deviation (3·03) is 6·33 per cent of mean. Without eliminating the heterogeneity, the standard deviation is 3·54, or 7·37 per cent of mean. The standard deviation before and after elimination of the soil differences are shown as percentages of mean for various plot sizes in Tables VII (*a*) and (*b*).

TABLE VII

Standard deviation of a single plot as per cent of the mean

	Length of plot				
	5 ft.	10 ft.	15 ft.	20 ft.	30 ft.
(*a*) *Before eliminating fluctuations due to fields, rows and columns*					
Width of plot—					
5 ft.	7·37	5·70	4·92	4·50	3·94
10 ft.	5·97	5·04	4·33	4·04	3·36
15 ft.	5·48	4·57	4·03	3·54	3·27
20 ft.	4·87	4·15	3·38	3·24	3·05
30 ft.	4·16	3·53	3·07	2·70	2·94
(*b*) *After eliminating fluctuations due to fields, rows and columns*					
5 ft.	6·33	4·85	4·14	3·89	3·20
10 ft.	4·98	4·18	3·58	3·57	2·14
15 ft.	5·21	4·56	4·40	4·16	4·15
20 ft.	3·62	2·96	1·83	2·18	1·50
30 ft.	2·76	2·18	1·74	1·49	1·65

SYSTEMATIC SOIL-DIFFERENCES

As plot size increases, either the row or the column or both increase in size, and the amount of systematic fertility differences eliminated is different in different cases. The total amount of variation eliminated is shown in Table VIII, in which column (1) gives the size of plot, column (2) the average sum of squares for variation due to field, rows and columns, and column (3) the mean residual variance.

TABLE VIII

Mean Squares of soil-heterogeneity and residual error for different plot sizes

Plot size	Mean Square	
	Soil-heterogeneity	Residual
5 ft. × 5 ft.	**30·1348 (45)	9·2031 (242)
5 ft. × 10 ft.	**72·9528 (33)	22·7157 (110)
10 ft. × 5 ft.	**66·3345 (33)	21·5476 (110)
15 ft. × 5 ft.	**95·2434 (29)	35·4134 (66)
5 ft. × 15 ft.	86·6525 (29)	56·02 (66)
10 ft. × 10 ft.	**183·0614 (21)	64·07 (50)
20 ft. × 5 ft.	*121·1467 (27)	55·5440 (44)
5 ft. × 20 ft.	**166·9010 (27)	47·9760 (44)
15 ft. × 10 ft.	*277·8899 (17)	105·7872 (30)
10 ft. × 15 ft.	209·9972 (17)	171·58 (30)
30 ft. × 5 ft.	*192·8350 (25)	84·3067 (22)
5 ft. × 30 ft.	**240·4479 (25)	63·0663 (22)
20 ft. × 10 ft.	365·1513 (15)	187·25 (20)
10 ft. × 20 ft.	**471·4306 (15)	128·4384 (20)
15 ft. × 15 ft.	291·6506 (13)	358·8998 (18)
10 ft. × 30 ft.	*700·9708 (13)	151·742 (10)
30 ft. × 10 ft.	*631·9015 (13)	156·59 (10)
20 ft. × 15 ft.	347·4507 (11)	571·4876 (12)
15 ft. × 20 ft.	**774·6905 (11)	110·2575 (12)
20 ft. × 20 ft.	*1079·1531 (9)	278·6736 (8)
30 ft. × 15 ft.	630·3538 (9)	1279·3644 (6)
15 ft. × 30 ft.	*1193·2188 (9)	224·1087 (6)
30 ft. × 20 ft.	*2032·3196 (7)	295·9856 (4)
20 ft. × 30 ft.	1654·4775 (7)	294·8038 (4)
30 ft. × 30 ft.	*5619·4918 (3)	808·1761 (4)

In column 1, 1st figure represents lengths in feet north to south, 2nd figure represents widths in feet east to west.

Double stars (**) indicate significance at one per cent and single star (*) at five per cent.

The figures in brackets in columns (2) and (3) give the degrees of freedom on which the variances have been calculated. Fisher's z-test shows that in practically all cases elimination of differences due to soil-heterogeneity lead to an appreciable improvement in accuracy.

DISCUSSION OF RESULTS

The first point to be noticed in Table VII (*a*) is that the first four figures in all the five columns show a steady decrease, the error for one-row wide plots being always the highest in each column. Compared to errors for one-row wide plots in Table VII (*b*) errors for two-row wide plots are much lower. The errors are again high for three-row plots, but decreased for four-row plots. This effect was noticed by Justesen [1932] and Kalamkar [1932] for potato, and was

attributed to the influence of competition between rows. Justesen suggested [1932, p. 369] that "a high yielding row will probably depress the yields of the adjacent row, in this way giving a high variation between rows. When these rows are paired, the pairs will tend to give an average with less variation than single row." It is possible that such a competitive effect also works between successive series of rice plots, but while the figures in the alternate rows of Table VII show some evidence of such an effect, yields in alternate columns are apparently not affected by competition, although conditions are presumably same along both ways for square-sized plots regarding spacing of plants.

The smallest error (1·50 per cent after elimination of soil-differences) occurs in six-row long and four-row wide as well as in four-row long and six-row wide plots, the size in both cases being 30 ft. × 20 ft. (=1/72·6 acre). The bigger plots as a rule show smaller errors than smaller ones, but the present experiment does not fully corroborate the claims made by a number of field workers that longer plots invariably show lower residual errors.

Efficiency of different plot sizes

In discussing the relative efficiency of plot-size, it is necessary to remember that, given a definite total area, the number of replications is reduced as the plot size is increased. Consider a fixed total size of field A. If the plot size is doubled the number of replications will be halved at the same time. If there is gain in precision due to increase in the size of the plot, there will be a loss of accuracy due to the consequential reduction in the number of replications. In determining the optimum size of plots, we must, therefore, take into consideration both the factors :—

(1) The increase of precision due to increased size of individual plots.

(2) The loss of precision due to the reduction in the number of replications.

Let e_a be the percentage error of a plot area "a," and n_a the available number of replications, then the standard error for the given plot-size "a" may be written —

$$E_a = \frac{e_a}{\sqrt{n_a}}$$

But $a.\ n_a$ = total area of field = A = constant. Thus

$$n_a = A/a \text{ or } 1/\sqrt{n_a} = \sqrt{(a/A)}$$

so that $E_a = e_a \sqrt{(a/A)}$.

Now E_a takes into consideration both sets of factors, errors appropriate to the given plot-size as well as to the available number of replications, and is thus a suitable criterion for testing the net efficiency of different plot sizes, the one with the smallest value of E_a being the most efficient. The values of E_a (where "a" is measured in multiples of the smallest plot as unit) are shown in Table IX (*a*) and (*b*).

TABLE IX

Standard deviation of a single plot after correcting for its size in per cent of the mean

		Length of plot				
		5 ft.	10 ft.	15 ft.	20 ft.	30 ft.
		(*a*) *Before eliminating fluctuations due to fields, rows and columns*				
(Width of plot)	5 ft.	7·37	8·06	8·52	9·00	9·65
	10 ft.	8·44	10·08	10·60	11·42	11·64
	15 ft.	9·49	11·19	12·09	12·26	13·87
	20 ft.	9·74	11·74	11·71	12·96	14·94
	30 ft.	10·19	12·23	13·02	13·23	17·64
		(*b*) *After eliminating fluctuations due to fields, rows, and columns*				
(Width of plot)	5 ft.	6·33	6·86	7·17	7·78	7·84
	10 ft.	7·04	8·36	8·77	10·10	7·41
	15 ft.	9·02	11·17	13·20	14·41	17·60
	20 ft.	7·24	8·37	6·34	8·72	7·35
	30 ft.	6·76	7·55	7·38	7·30	9·90

Table IX differs considerably from Table VII. Plots of size 30 ft.×20 ft. (six-row×four-row and four-row×six-row) showed the smallest residual standard deviations in Table VII, but in Table IX the highest precision is given by the smallest plot 5 ft.×5 ft. The smallest plot-size in this experiment provided such a large number of replications that the gain in accuracy due to this factor more than compensated for the loss of precision due to the reduction in the actual size of plots.

The results given in Table IX are shown in percentage form in Table X in which the residual errors for the different plot sizes are shown expressed as percentage of the residual error for the smallest plot. (That is, the residual error of the unit plot (5 ft.×5 ft.) after eliminating soil heterogeneity is taken=100).

Table X

Percentage standard deviation of a single plot expressed as a percentage of the minimum plot (5 ft.×5 ft.) with the errors for fields, rows and columns eliminated

(Width of plot)	Length of plot: 5 ft.	10 ft.	15 ft.	20 ft.	30 ft.
(a) Without eliminating the fluctuations due to fields, rows and columns					
5 ft.	116·42	127·33	134·60	142·18	152·45
10 ft.	133·33	159·24	167·46	180·41	183·89
15 ft.	149·92	176·78	191·00	193·68	219·12
20 ft.	153·87	185·47	184·99	204·74	236·02
30 ft.	160·98	193·21	205·69	209·01	278·68
(b) Eliminating the fluctuation due to fields, rows and columns					
5 ft.	100·00	108·37	113·27	122·91	123·86
10 ft.	111·22	132·07	138·55	159·56	117·06
15 ft.	142·50	176·46	208·53	227·65	278·04
20 ft.	114·38	132·23	100·16	137·76	116·12
30 ft.	106·79	119·27	116·59	115·33	156·40

Fisher presents similar results in terms of "efficiency", where the "efficiency" Fa is defined to be inversely proportional to E_a^2, that is

$$Fa \propto 1/E_a^2$$

Thus in order to express the results in terms of Fa, we have simply to take the square of the reciprocals of the figures given in Table X. It is clear that the unit plot (5 ft.×5 ft.) would give the highest value of Fa, showing its maximum efficiency in the Fisherian sense.

For the convenience of comparison, the values of Fa are given in Table XI.

Table XI

Relative efficiency of plots of different shapes and sizes (Fa).

(Width of plot)	Length of plot: 5 ft.	10 ft.	15 ft.	20 ft.	30 ft.
(a) Without eliminating the fluctuations due to fields, rows and columns					
5 ft.	73·78	61·67	55·19	49·47	43·02
10 ft.	56·25	39·42	35·66	30·72	29·57
15 ft.	44·48	32·00	27·40	26·65	20·83
20 ft.	42·23	29·07	29·21	23·85	17·95
30 ft.	38·58	26·79	23·63	22·89	12·87

TABLE XI—*contd.*

Relative efficiency of plots of different shapes and sizes (Fa).

(Width of plot)	Length of plot: 5 ft.	10 ft.	15 ft.	20 ft.	30 ft.
(b) After eliminating fluctuations due to fields, rows and columns					
5 ft.	100·00	85·15	77·95	66·18	65·18
10 ft.	80·84	57·33	52·08	39·27	72·97
15 ft.	49·23	32·11	22·99	19·28	12·93
20 ft.	76·44	57·13	99·68	52·80	79·15
30 ft.	87·68	70·29	73·56	75·18	40·88

It is worth noting that the results for net efficiency (as given in Table X or Table XI) show considerable irregularities, although a few systematic features are also present. Thus one-row wide plots are usually considerably more efficient than two-row and three-row wide plots ; also one-column long plots are on the whole the most efficient. The three most efficient plot sizes on the other hand are quite irregular and are given by one-column × one-row (5 ft. × 5 ft. = 1/1742·4 acre with a value of $Ea = 100$), three-column × four-row (15 ft. × 20 ft. = 1/145·2 acre ; $Ea = 100·2$), and one-column × six-row (5 ft. × 30 ft. = 1/290·4 acre ; $Ea = 106·8$).

It is scarcely necessary to add that convenience of agricultural operations such as the laying out of the field, tillage, ploughing, harvesting, etc., as well as the relative economic cost of such operations must also be taken into consideration in fixing the optimum size of plots. The results of the present experiment show however that fortunately the range of choice from the point of view of purely statistical efficiency is likely to be quite wide. For example in this particular experiment, the difference in statistical efficiency between plot-sizes of 5 ft. × 5 ft. (= 1/1742·4 acre), 5 ft. × 30 ft. (= 1/290·4 acre), and 15 ft. × 20 ft. (= 1/145·2 acre) is quite small, so that the final choice can be easily made from the point of view of practical convenience.

SUMMARY

The present paper gives an analysis of a uniformity trial on transplanted rice (*As.2 Kasalath* of *Aus* type) conducted in the Karimganj Farm, Assam, in 1933-34 in the form of two Latin Squares with 12 rows × 12 columns each.

(1) The observed frequency distributions of the yield figures for each Latin Square as well as for both combined are not significantly different from normal, and can be graduated quite satisfactorily by the normal curve. The assumption of a normal distribution of plot yields is, therefore, justified within the limits of sampling errors of the present experiment.

(2) The results were analysed in detail by the method of analysis of variance for all possible (25 different) size and shape of plots. In practically every case the

elimination of variation due to systematic differences in soil-fertility led to an appreciable decrease in the residual errors.

(3) There was some evidence of the presence of competition between rows, but not between columns, although conditions of spacings between plants were apparently the same along both directions so far as the lay-out was concerned.

(4) The smallest residual variance occurred with plots of size 30 ft.$\times$20 ft. (6-row$\times$4-row=1/72·6 acre) which was the second largest size analysed in this experiment.

(5) Taking into consideration the effect of reduction in the number of replications due to an increase in the size of individual plots, the net residual error is lowest in the case of the smallest plot-size (5 ft.$\times$5 ft. =1/1742·4 acre). The difference in net efficiency of comparison is, however, small with plot sizes of 5 ft.$\times$ 5 ft, 5 ft.$\times$30 ft., and 15 ft.$\times$20 ft., so that the range of choice is fairly wide for fixing the optimum size of plots from considerations of practical convenience.

Fairly small-sized plots (of the order of 1/1742·4 or 1/145·2 acre) are thus statistically quite efficient for experiments on rice.

It is a pleasure to express our indebtedness to Dr. S. K. Mitra, Economic Botanist, Assam, for his kind encouragement in the present investigation. Our thanks are also due to Mr. S. K. Banerjee of the Statistical Laboratory for his valuable help in the statistical analyses.

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STATISTICAL NOTES FOR AGRICULTURAL WORKERS

No. 20—STUDIES IN TILLER VARIATION

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Introduction

Rice, like many cereals, has the capacity of producing side-shoots ; this is called tillering in rice. The shoots are produced from the axil of the leaf, the tillering zone being confined to a small portion of the base of the rice plant where internodes are close, although in deep water paddies the tillers come out from any node. Usually the tillers are produced on alternate sides of the main stem ; these secondary shoots in turn produce tertiary ones and so on.

Under normal conditions of cultivation, rice plants begin to tiller a week after transplanting. In early *Aus* varieties tiller formation may cease from the fifth or the sixth week but in late varieties it may extend up to the eighth or the ninth week. This limiting period may be termed the critical stage of tiller formation, after which the tillers grow up and produce stems each carrying an ear.

The average number of tillers per plant is a varietal characteristic, different varieties producing different number of tillers. In fact, the yield of a variety depends a good deal on its tillering capacity, which is, therefore, considered to be an important economic factor in the study of the rice plant. All tillers, however, are not equally effective in contributing to the final yield ; thus, under heavy manuring or very wide spacing, tillering may continue till the flowering stage, but these tillers do not ripen with the earlier tillers and may not yield grains. They mostly waste the energy of the plant without any corresponding return.

In classifying rice considerable weight is given to the study of the nature and number of tillers formed, and recent work on rice in Assam, Bengal and Madras go to show the importance of tiller studies. In the present investigation, range of

variation of tillers from plant to plant of a given variety of rice, the nature of the distribution of tillers, and the effect of soil heterogeneity on tiller numbers have been studied from a statistical standpoint, and an attempt has been made to determine the order of accuracy of the estimates for a given number of tiller counts.

The present tiller test was conducted at the Government Agricultural Farm, Bankura, in 1933-34. Three blocks of land measuring 1/10 acre each were transplanted with single plants of *Jhingasail* a local variety of rice grown very frequently in Western Bengal. The blocks were laid out in the form of 5×5 Latin Squares, and each plot contained ninety plants in nine rows of ten columns each with a spacing of nine inches from plant to plant. The dates of transplanting were different in the three blocks and are given below :—

Field No. 37/B	13th July, 1933.
Field No. 36/B	27th July, 1933.
Field No. 35/B	7th August 1933.

The total number of plants in each block was $90 \times 25 = 2,250$, so that in three blocks there were 6,750 plants altogether. The number of tillers grown on each of these plants was counted by one of us (K. C. B.) with the help of Mr. J. R. Pal, Assistant Rice-Research Officer, Bankura, and these records form the material for the present note.

Range of variation

Omitting three plants in blocks 37/B and 35/B, and two plants in block 36/B which had died, tiller formation ranged up to seventeen per plant in 37/B, and fourteen in each of 36/B and 35/B. The range of mean tillers per plot of ninety plants in the three blocks together with the range of standard deviations are shown in Table I.

Table I

Range of variation of mean and S. D. of tillers

Block	Range of variation	
	Mean	S. D.
37/B	5·24—9·33	1·10—2·17
36/B	5·42—8·41	1·02—2·08
35/B	3·87—7·60	1·11—2·03

The mean tiller numbers per plant for each of the twenty-five plots in blocks 37/B, 36/B and 35/B together with the standard deviations are shown in Appendix I. The statistical analysis is given in Table II.

TABLE II

Analysis of variance

	D. F.	Sum of squares	Mean square	Ratio
(a) Field 37/B				
Rows	4	1323·97	330·99	5·42
Columns	4	156·61	39·15	0·64
Residual	16	976·97	61·06	
Total	24	2457·55		
(b) Field 36/B				
Rows	4	91·90	22·98	0·71
Columns	4	244·50	61·13	1·90
Residual	16	514·59	32·16	
Total	24	850·99		
(c) Field 35-B				
Rows	4	1067·33	266·83	6·54
Columns	4	153·58	38·40	0·94
Residual	16	653·05	40·81	
Total	24	1873·96		
(d) Three fields combined				
Rows	12	2483·20	206·93	4·63
Columns	12	554·69	46·22	1·03
Field	2	24924·12	12462·06	278·92
Residual	48	2144·61	44·68	
Total	74	30106·62		

It will be seen from the above tables that the mean square deviation " between columns " were always of the same order as the residual variance. The row variance, however, was very large in blocks 37/B and 35/B, but not in 36/B. The variances for tillers per plot were roughly of the same order in all three fields, and were 61·06, 32·16 and 40·81 respectively ; pooling these results, the variance was 44·68, so that the standard deviation between tillers per plant in the plots of ninety plants each is 6·7 approximately.

Since data for individual plants have been recorded, it is possible to make an estimate of systematic soil differences within the same plot. There are ninety plants in each plot arranged in ten rows and nine columns ; the mean variances of tillers per plant between rows and columns are shown in Appendix II (*a*)-(*c*) together with the residual and total variances. It will be seen that, with the exception of a few plots, the row and column variances were not significant. Hence as

far as the tiller counts are concerned each plot appeared fairly homogeneous within itself, although the whole field of twenty-five plots showed appreciable soil differences between rows (Table II).

The frequency constants together with the standard errors are shown in Table III. We notice that block 37/B gives the highest mean tiller per plant, block 36/B comes next, with block 35/B as significantly the lowest. The standard deviations in the three blocks, though statistically differentiated, are fairly close to each other and the pooled standard deviation of tillers per plant is 1·92.

TABLE III

	Frequency constants with standard errors			
	Observed values			Expected
	37/B	36/B	35/B	
Size of sample	2250	2250	2250	
Mean .	7·2249 ±0·0425	6·6498±0·0380	5·9334±0·0409	
Standard Deviation	2·0160±0·0301	1·8013±0·0269	1·9402±0·0289	
β_1 .	0·0551±0·0263	0·0547±0·0202	0·2637±0·0576	0·0000
β_2 . .	3·3436±0·2003	3·0497±0·1259	3·2809±0.1841	3·0000

The β/values in the first two blocks (37/B and 36/B) are not significantly different from zero so that these distributions may be taken to be symmetrical. The distribution of tillers in block 35/B is, however, appreciably skew, the bias being on the side of lower value. The β_2 values in the three cases are not significantly different from 3 (=the value of β_2 in the case of normal curves). The histograms for these three observed distributions are shown in Figs. 1—3.

So far as the first four moments are concerned, the distribution of the number of tillers per plant in the first two blocks cannot be distinguished from a normal type. The distribution in the third block is slightly skew and rather abruptly rises to a maximum and then slowly tails off at either end ; but even then, the deviations of β_1 and β_2 from Gaussian values are not very marked.

The observed frequencies were next graduated by a normal curve with mean value and variance based on the sample. The observed and expected frequencies are given in Table IV and also in Figs. 1—3.

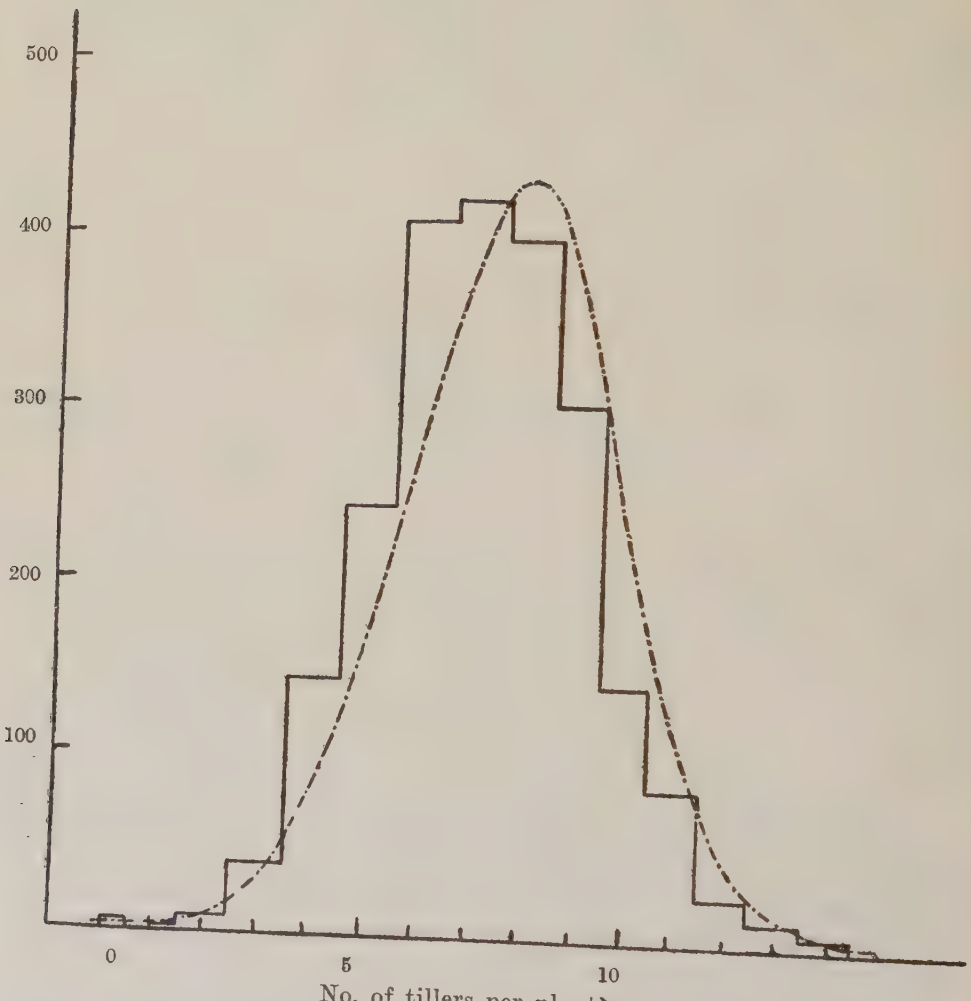

Fig. 1. Frequency distribution of tillers in field 37/B.

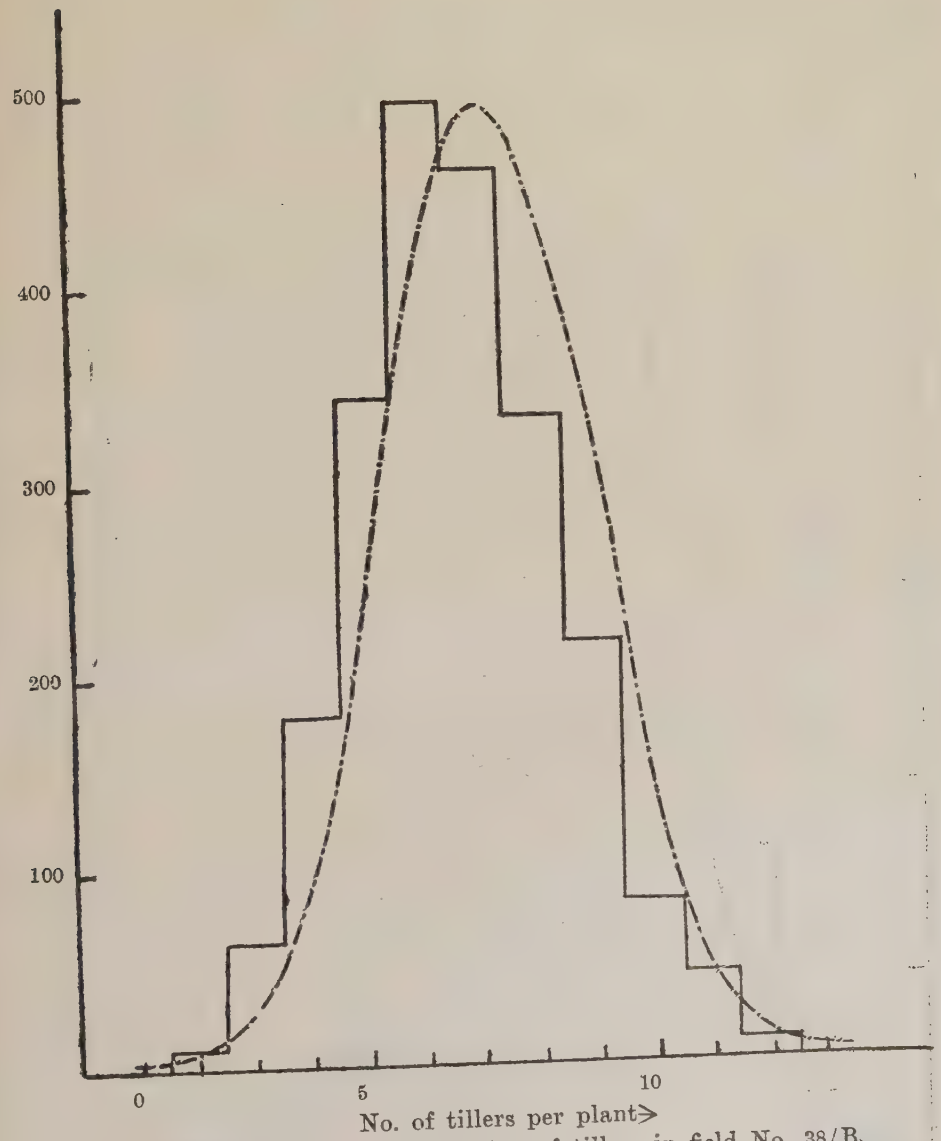

Fig. 2. Frequency distribution of tillers in field No. 38/B.

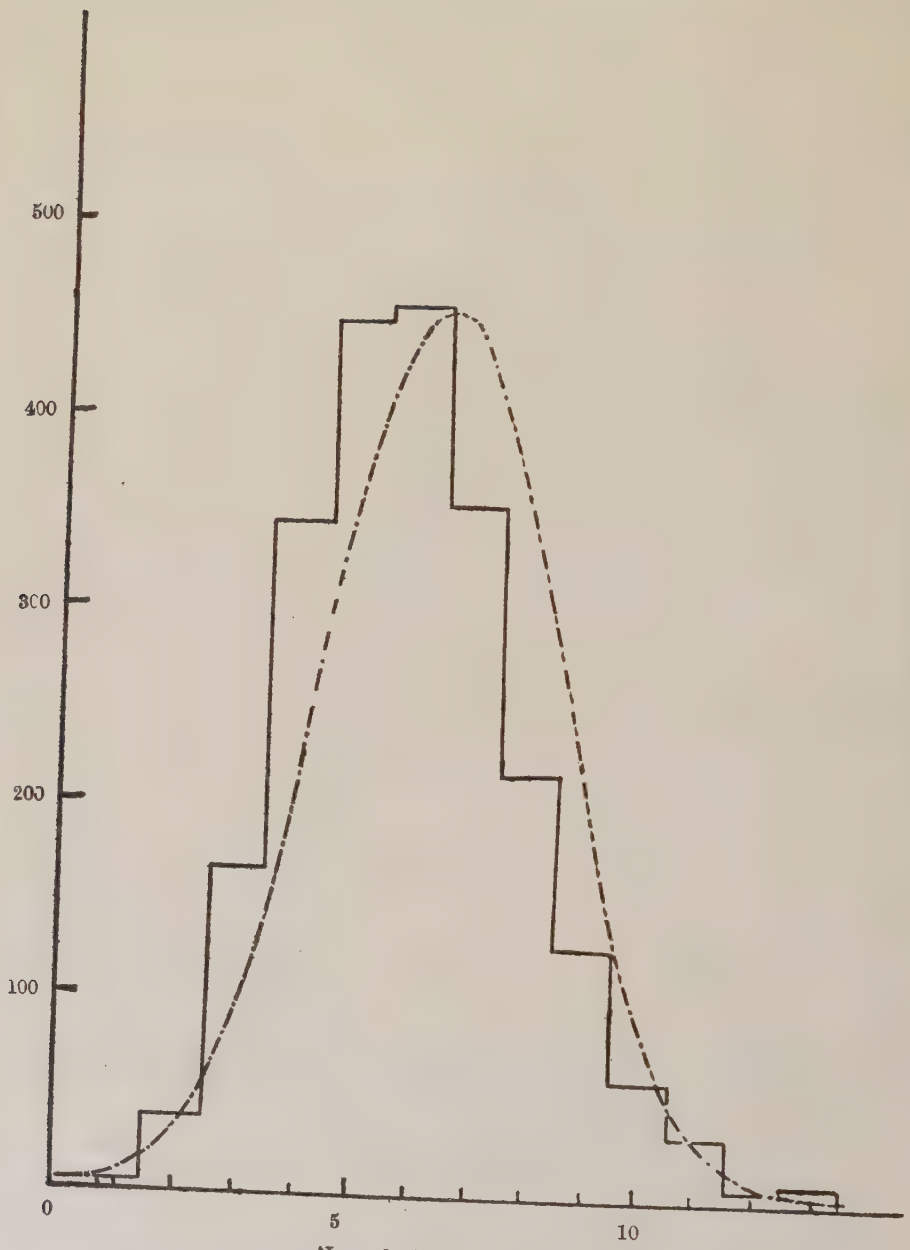

Fig. 3 Frequency distribution of tillers in field No. 35/B.

TABLE IV

Observed and calculated frequency distribution of tillers and (P,χ^2) test

No. of tillers	Field 37/B			Field 36/B			Field 35/B		
	Observed (f′)	Calculated (f)	$(f-f')^2/f$	Observed (f′)	Calculated (f)	$(f-f')^2/f$	Observed (f′)	Calculated (f)	$(f-f')^2/f$
0	3	0·45	14·45	2	0·22		0	2·70	2·70
1	1	1·80	0·36	0 } 11	1·80 } 11·02	0·02	3	9·90	4·81
2	7	8·55	0·28	9	9·00		38	35·55	0·17
3	37	29·70	1·79	63	36·90	18·46	166	99·00	45·34
4	144	82·80	45·23	180	110·93	43·01	342	212·18	79·43
5	245	180·00	23·47	344	245·70	39·33	447	351·00	26·26
6	410	307·80	33·93	498	403·20	22·29	455	442·80	0·34
7	421	413·58	0·13	463	490·27	1·52	353	441·23	17·64
8	400	436·72	3·09	336	442·13	25·48	215	332·78	41·69
9	305	362·47	9·11	219	293·85	19·07	127	194·40	23·37
10	145	236·25	35·24	82	145·35	27·61	59	87·97	9·54
11	87	121·05	9·58	44	52·87	1·49	33	30·37	0·23
12	26	48·60	10·51	8	14·40		4	7·87	1·90
13	12	15·52	0·80	1 } 10	2·92 } 17·78	3·40	7	1·80	15·02
14	5	3·82	0·36	1	0·46		1	0·23	2·58
15	1	0·67	0·16						
16	0 } 1	0·22	2·76						
17	1								
	2250	2250·0	$\chi^2=191·26$ $P<10^{-6}$	2250	2250·00	$\chi=201·68$ $P<10^{-6}$	2250	2249·78	$\chi^2=271·02$ $P<10^{-6}$

A glance at the diagrams shows that the fit is totally inadequate The same conclusion is reached from the very high values of (P, χ^2). In fact, the odds against the samples having been drawn from a normal population are considerably greater than a million to one.

At first sight it may appear a little strange that an observed distribution for which the two conditions $\beta_1=0$, and $\beta_2=3$ are approximately satisfied does not admit of even a moderately adequate fit by a normal curve. The reason, however, is clear. If an observed distribution is truly normal not only its first four moments but the higher moments also must agree with the theoretical values within the limits of errors of sampling. The method of classifying an observed distribution with the help of moment functions is only tentative; actual graduation by the expected type and comparison of observed values by the (P, χ^2) test is always desirable.

In the present case the χ^2-test shows conclusively that the distribution of tillers per palnt cannot possibly be considered to be of the normal type. It remains now to be examined how far the use of Fisher's z and t-tests are adequate when the population to be sampled is of this type.

Summary

The number of tillers in each of 6,750 rice plants grown in Bankura Farm in 1934 were counted and the observations have been analysed for investigating into (*i*) the range of mean and standard deviation of tillers from plot to plot, (*ii*) the nature of frequency distribution of tillers and (*iii*) the effect of soil differences on tiller number.

(1) Mean tillers per plant based on a sample of 90 ranged between 3·87 and 9·33.

(2) Standard deviation of tiller number varies between 1·02 and 2·17. The pooled standard deviation is 1·92 tillers per plant.

(3) The variance between rows was significant. The tiller numbers within plots of 1/250 acre did not show appreciable heterogeneity.

(4) The distribution of tillers was not significantly different from the normal type as far as the first four moments. The higher moments were, however, significantly different from those of normal distribution, and thus the normal curve was inadequate for graduating the frequency distribution of tillers. This was also confirmed by (P, χ^2) values.

Acknowledgments

We have great pleasure in acknowledging our gratefulness to Mr. K. McLean, Director of Agriculture, Bengal, and to Mr. S. G. Sarangapani, Economic Botanist, Bengal, for their kind interest in this investigation. Thanks are also due to Mr. J. R. Pal, B.A., Assistant Rice Research Officer, Bankura and to Messrs.

P. Mitter and A. Latif, Fieldmen, for the great trouble they took in counting tillers from 6,750 plants, The work was rendered possible by a research grant from the Imperial Council of Agricultural Research.

Appendix I

Mean value of number of tillers based on 90 plants and their standard deviations

Serial No.	Field No. 37/B		Field No. 36/B		Field No. 35/B	
	Mean	S. D.	Mean	S. D.	Mean	S. D.
1	6·61	1·488	5·57	1·955	4·96	1·105
2	5·24	1·621	6·64	1·668	3·87	1·230
3	5·93	1·344	7·06	1·702	4·16	1·307
4	6·44	1·175	6·74	1·582	4·91	1·547
5	6·53	1·833	8·41	1·885	4·87	1·127
6	5·41	1·994	7·38	1·901	5·62	1·352
7	6·09	1·465	6·44	1·661	6·40	1·890
8	7·07	1·537	6·58	1·795	6·53	1·157
9	7·33	1·542	6·56	1·017	6·64	1·728
10	7·54	1·627	5·50	1·753	3·98	1·549
11	6·29	2·088	6·51	1·327	5·71	1·797
12	7·27	1·724	5·70	1·696	6·68	1·858
13	7·37	1·487	6·02	1·422	4·62	1·409
14	7·49	1·734	6·63	1·622	7·60	1·756
15	6·52	1·878	7·86	1·716	6·56	1·472
16	8·60	1·872	6·56	1·480	5·83	1·655
17	6·69	2·174	7·36	1·448	5·69	1·658
18	9·33	2·033	5·42	1·591	6·58	1·542
19	8·44	1·826	6·14	1·596	7·20	1·477
20	7·60	2·077	6·22	1·364	6·77	1·897
21	8·64	1·815	6·78	1·638	7·44	2·026
22	9·13	1·691	6·61	2·080	6·74	1·777
23	7·72	2·129	7·56	1·586	6·70	2·003
24	7·74	1·102	7·32	1·787	6·77	1·726
25	7·24	1·515	6·60	2·010	5·53	1·634

Appendix II

Mean variance of rows, columns and residue

Serial No. of the plot.	Row (9)	Column (8)	Residue (72)	Total (89)
		(*a*) *Field 37/B*		
1	2·48	2·59	2·16	2·2403
2	2·77	3·65	2·55	2·6587
3	2·94	1·73	5·05	1·8270
4	*2·19	**3·54	1·04	1·3958

** Indicate significance at one per cent.
* Indicates significance at five per cent.

APPENDIX II—*contd.*

Serial No. of the plot	Row (9)	Column (8)	Error (72)	Total (89)
		(*a*) *Field No. 37/B*—contd		
5	5·77	4·73	2·97	3·3978
6	2·08	2·45	4·43	4·0201
7	3·11	1·68	2·13	2·1718
8	2·45	4·09	2·17	2·3888
9	2·78	3·80	2·20	2·4045
10	3·68	1·80	2·67	2·6778
11	3·89	2·57	4·70	4·4100
12	2·84	6·13	2·62	3·0067
13	1·03	2·91	2·29	2·2348
14	3·22	2·13	3·27	3·0388
15	2·89	4·26	3·56	3·5782
16	2·03	6·53	3·34	3·5461
17	3·21	**12·77	3·97	4·7785
18	4·36	2·42	4·39	4·1798
19	3·17	3·56	3·37	3·3733
20	4·52	1·28	4·67	4·3620
21	3·01	3·48	3·35	3·3328
22	2·20	2·61	3·00	2·8921
23	4·94	7·44	4·21	4·5849
24	**3·98	**2·36	0·73	1·2261
25	1·95	1·99	2·40	2·3216
		(*b*) *Field No. 36/B*		
1	**16·4802	1·6750	2·5332	3·8663
2	1·9864	5·3278	2·6366	2·8126
3	2·4506	2·9278	2·9897	2·9295
4	0·7173	2·2528	2·7870	2·5295
5	4·0136	3·0861	3·5972	3·5931
6	4·9334	4·0945	3·4374	3·6534
7	2·6667	3·2778	2·7502	2·7890
8	5·1556	2·3445	3·1225	3·2579
9	**6·2963	2·8778	1·7297	2·2946
10	1·8086	2·8500	3·2978	3·1068
11	1·2642	*3·7361	1·6282	1·7808
12	3·0383	2·2750	2·9634	2·9090
13	2·7358	2·1195	1·9499	2·0445
14	4·0259	*5·0000	2·2317	2·6618
15	3·0630	4·9278	2·7520	2·9789
16	3·5309	6·3528	3·1339	3·4632
17	1·0568	3·2278	2·1292	2·1194
18	3·5506	*5·2445	2·1396	2·5613
19	2·3716	*5·8528	2·2357	2·5744
20	**4·2963	**5·1945	1·2130	1·8827
21	4·3951	4·0695	2·3535	2·7141

** Indicate significance at one per cent.
* Indicates significance at five per cent.

APPENDIX II—*concld.*

Serial No. of the plot	Row (9)	Column (8)	Error (72)	Total (89)
		(*b*) *Field No. 36/B*—contd		
22	3·1914	4·1611	4·5473	4·3752
23	*4·6284	**5·6028	1·9424	2·5430
24	5·1963	*6·0445	2·6742	3·2321
25	1·7086	7·2000	4·0367	4·0854
		(*c*) *Field No. 35/B*		
1	1·0667	1·8778	1·1833	1·2340
2	1·8222	0·7972	1·5750	1·5301
3	1·7827	1·8778	1·7049	1·7283
4	3·8469	3·5861	2·1108	2·4190
5	0·7605	**3·1750	1·1411	1·2854
6	1·7580	1·8111	1·8636	1·8482
7	3·2395	3·3000	3·6951	3·6135
8	*3·3086	1·1528	1·5725	2·5194
9	3·7235	2·2028	3·0207	3·0182
10	**10·0938	**2·4444	0·3549	2·4265
11	1·6840	*6·5611	3·0951	3·2639
12	*6·0605	*6·2444	2·8772	3·5017
13	2·0691	2·2278	1·9747	2·0070
14	*5·9556	3·3000	2·7444	1·9955
15	2·9630	5·0278	3·3241	3·4407
16	0·7901	3·7347	3·2332	3·0312
17	3·6247	2·3111	3·7247	2·7785
18	*4·2148	3·6167	2·0429	2·4040
19	**3·1556	**3·3445	1·1500	1·5501
20	1·8630	5·3500	3·6741	3·6416
21	6·2469	2·4528	4·0886	4·1598
22	3·6308	3·1778	3·1392	3·1924
23	4·6038	7·3863	3·6176	4·0561
24	2·9000	2·1500	3·1222	3·0124
25	2·1926	1·9000	2·8537	2·7011

**Indicate significance at one per cent.
* Indicates significance at five per cent.

SELECTED ARTICLE

METHODS OF ANALYSIS AND APPRECIATION OF WHEAT, FLOURS AND BREAD, PARTICULARLY IN RESPECT OF INVESTIGATIONS ON THE BAKING VALUE

(SECOND PART)

BY

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CHAPTER II

ANALYSIS OF FLOURS

The quality of the flour is the fundamental basis of good bread and it cannot be estimated in relation to a single factor only. The data that must be taken into consideration when judging whether a flour is suitable for bread-making are many and complex. Bread is in no sense an inert, but rather a living organism, in which are to be found numerous chemical and bio-chemical phenomena that, as will be seen later, have an important influence on its quality.

The tests to which flours must be submitted are the following: (A) Physical and organoleptic—(B) Chemical—(C) Bio-chemical—(D) Physico-chemical—(E) Mechanical.

Before discussing the methods of analysis, it is necessary to mention briefly the taking and preparation of samples.

Taking of samples.—This operation should be carried out with care and accuracy in order to obtain a homogeneous sample which corresponds with the flour from which it is taken. Special instruments, called sampling rods, allow material to be taken at varying depths, either from the sack or in the warehouse in which the flour is stored.

The samples are then mixed together according to the methods used for mixing the grain and the prepared sample is placed in a sealed tin treated with paraffin and kept until required for use.

(*A*) *Physical and organoleptic examination*

This is divided into : examination by touch (to ascertain the degree of softness of the flour, whether it contains lumps, etc.)—examination of the odour—examination of the taste—examination of the colour—examination of the fineness.

Examination of the odour.—The odour of the flour should be the same as that of wheat. When there is any doubt, the odour may be brought out by boiling the flour in water with a small quantity of caustic soda.

Examination of the taste.—The taste should be that of wheat. If the taste is unpleasant or abnormal, the flour has either not been properly preserved or else contains some foreign substance.

Examination of the colour.—This is carried out to a large extent both in the milling industry and in the trade. The colour of the flour gives a fairly accurate idea of quality both as regards bolting and the presence of foreign bodies which affect its purity. The determination of the colour of the flour may be divided into : determination of whiteness (reflected colour)—determination of the chemical constituents which give colour to the flour.

The determination of colour by reflection does not clearly indicate the content in chemical elements which give colour to flours. The factors which determine the greatest differences in colour are as follows : (1) content in bran—(2) content in carotin—(3) presence of impurities and foreign bodies, such as dust, weed seeds, rust, spores, etc.

The content in bran depends on the system of milling employed : the content in carotin on the variety of wheat milled. The variations in colour, due to foreign substances, are chiefly dependent on the colour of such substances, but may also be due to other causes, such as the oiliness of seeds in the flour, which cause variations in the absorption of light. According to some authorities enzymatic activity, particularly that of oxidizing ferments, may also influence the colour of the flours. In addition to these factors there are others among which may be mentioned : (1) the coarseness of the grains—(2) the moisture content—(3) the degree of pressure exercised—(4) the intensity and direction of the light under which the examination is made.

It is, therefore, evident that in determining the whiteness of the flour there are many possible causes of error. The Pekar method, however, has remained the basic process followed for a rapid determination of colour in the practice both of the flour industry and of the flour trade (*i*)*.

Pekar method.—On a black smooth wooden board about 12 cm. long by about 8 cm. wide, small four-sided blocks of flour are made by means of stamps (5 cm. long, 3 cm. wide, 5 mm. thick). The board is then carefully placed at a slanting angle in a basin of hot water and left for about one minute ; it is then slowly

* The figures in parenthesis refer to the explanatory and bibliographical notes pp. 1150—1152.

removed and dried at 100° and the difference in colour is noted, which is much more apparent when the flour is completely dry.

Examination of the colour of flours.—Numerous methods are used which, according to the quantity and quality of the solvent used, lead to different and divergent results.

For researches on the colour (carotin) the Kent Jones method (2) has been adopted. For this there are required :—

(1) a Duboscq colorimeter : better results are obtained with the Pulfrich photometer and colorimeter with photo-electric cells (Lange apparatus),

(2) reagents : (*a*) benzine ; density, 0·720-730 ;

(*b*) a coloured solution obtained by using the following mixture : 10 c.c. of solution of potassium chromate at 0·5 per cent, 1·5 c.c. of solution of nitrate of cobalt anhydride at 10 per cent of solution. The whole is brought to 100° with distilled water.

The procedure is as follows : 20 grm. of flour is placed in a graduated tube, 100 c.c. of benzine is added and the whole is mixed and shaken in an agitator for one hour, after which it is left to stand for a night. The liquid is then separated from the precipitate, filtered (using filter No. 601-602) and the clear solution is compared with the sample.

Determination of fineness.—The sieving test may be carried out by hand by means of a series of small sieves with varying fineness of mesh. At the present time small electric " plansichters " are used, which answer the purpose perfectly and allow the various degrees of fineness of the flours tested to be studied.

(*B*) *Chemical methods*

Chemical tests comprise the following determinations moisture—ash—cellulose—protein substances—fats—gluten—sugars—acidity.

The determination of moisture, ash, fats and protein substances is carried out as for wheat.

Determination of cellulose.—The Weenden method adopted for wheat is also highly suitable for flours. Mention should also be made of the recently proposed Kurschner and Hanack method (3), introduced by Bellucci (4) for his experiments on flour, which is highly recommended for its rapidity and accuracy.

In a glass sphere, capacity 100 c.c., to which is attached a glass tube 1 metre long and 5 mm. in diameter, is placed a liquid reagent thus composed : 45 c.c. of acetic acid at 1·80 per cent in weight and 4·5 c.c. of concentrated nitric acid (p.s.—1·4) if the sample examined is flour or forage meal ; 30 c.c. of acetic acid and 3 c.c. of nitric acid for other by-products. By means of funnel 3 grm. of baking flour are introduced (2 grm. of forage meal or 0·3 grm. of other by-products), the refrigerating tube is applied and heating takes place by means of a small flame

taking care to avoid carbonisation of the substance. The flame is regulated and the heating at low boiling point is carried out for 25 minutes in such a way as to avoid the escape of steam from the refrigerating tube. Filtration is then carried out on a porous crucible. The glass sphere is washed with 5 c.c. of hot reagent, then with hot water, a little alcohol, ether and finally with hot water again. The crucible is placed in an oven at 105° for one hour and then weighed. It is then calcinated and weighed again. The difference between the two weights gives the value of the crude ash-free cellulose.

Determination of gluten.—The most important chemical tests are those made on the gluten and its constituents, as the baking value of the flour is chiefly dependent on this substance.

Gluten is formed by the action of water. In the cells of the wheat there are two gluten forming proteids which, under the action of water, are transformed into gluten. Gluten is considered to be formed by gliadin and glutenin and is not a simple mixture, but, according to Bugenberg de Jong, is a colloid complex, based on an electric relation between the two substances. It is evident that in extracting the gluten many variations may occur due to the system of extraction adopted and also to the physico-chemical conditions.

The content in gluten of a wheat and its qualities are clearly not only dependent on the quantity of nitrogenous substances and consequently on all the factors already described having an influence on the wheat (variety, conditions of cultivation, soil, climate, etc.), but are also influenced by other factors, among which should be mentioned the fineness of the milling and the conditions under which the gluten is extracted, such as the hardness and composition of the water employed, the length of time the dough is left to stand, the temperature of the water, the length of time employed in washing the gluten, the methods of the individual operator, etc.

It is, therefore, clear that it is necessary to standardize as far as possible the methods of extraction in order to arrive at corresponding and comparable results.

Many processes are now in use ; frequently spring water is used which, having a composition that varies from place to place leads to considerable variations. Marotta and Vercillo (5) adopted in their experiments the solution of the type advised by Berliner and Koopmann (6). This is a solution of sodium chloride free from magnesia, which, with the addition of sodium phosphate, is brought to the ionic concentration considered by Dill and Alsberg as being the best for preventing dispersion of the gliadin (7).

Extraction of gluten.— In order to eliminate any influence due to the operator or to working conditions, it has been considered advisable to abandon the system of hand extraction and to use solely mechanical means. True extraction is carried out with the Hankoczy apparatus and for freeing the gluten from the starch still present, we use our own separator which in its method of operation resembles that of the machine adopted in the industry for the preparation of gluten as well as Arpin's " Essoreuse."

The method of procedure is as follows : 50 grm. of flour are kneaded for 5 minutes with 20 c.c. of standard solution (8) and the dough obtained is left to stand for half an hour after which two morsels of dough, 20 grm. in weight, are taken and placed in the two rubber bags of the Hankoczy apparatus and double extraction is carried out so as to obtain more accurate results. During the operation the standard solution kept at 18° is slowly dropped in until the washing water is clear.

It should be noted that the gluten thus extracted is not free from starch ; in fact, if the protein content is determined (allowing that the protein substances are equal to nitrogen $\times 6 \cdot 25$) it will be seen that the gluten contains 75-87 per cent of protein substances and that the remainder consists of starch, fats, minerals, etc.

After carrying out the extraction, the two pieces of gluten previously extracted are passed through two steel cylinders revolving in opposite directions, about a tenth of a millimetre apart. This operation takes place under a jet of standard solution and is completed in 40 minutes. In this way the greater part of the starch is expelled and the results are in agreement.

In our analysis we take, as already said, the average between the two weights, which are generally equal. This weight multiplied by 5 gives the content in wet gluten of 100 parts of flour ; the dry gluten is obtained by drying the wet gluten in an oven at 105° for 12 hours, taking care to cut the surface of the gluten crosswise after half an hour in the oven so as to facilitate the evaporation of the water.

* * * * *

Is the gluten content sufficient for estimating the quality of a flour and is there any constant relation between this quantity and the baking strength ?

Undoubtedly a good flour always contains a considerable percentage of gluten (generally a limit of not less than 8 per cent is required) and the absence or insufficiency of gluten renders the flour unsuitable for baking. It should, however, be observed that, although the strength of the flour is dependent on the presence of gluten, this is not dependent only on the quantity but also on the quality of that substance which is in relation to its physical and physico-chemical properties.

(*i*) *Dosage of gliadin and glutenin*

Research work on the constituents of gluten has been the subject of numerous studies made with a view to the estimation of the baking strength of flour. Some writers are of opinion that the relation gliadin : glutenin is a sufficiently accurate criterion for estimating the quality of the flour. The methods of extraction, however, employed by them are so diverse that the results contradict each other and no final conclusions can be reached. According to Snyder (9) the percentage of gliadin is much more important than the relation gliadin : glutenin.

Fleurent (10) believes that the most satisfactory relation gliadin : glutenin is 1/3, while Sharp and Gotner, using alcohol at 70°, found for flour a relation gliadin : glutenin which varies little and approximates to unity.

Determination of gliadin.—Ten grm. of flour are added to 100 c.c. of alcohol at 70° in a glass tube, with a roughened stopper, shaken frequently during the day. It is then left to stand for a night and shaken again in the morning, and filtered, after the flour has been deposited. The total nitrogen in 50 c.c. of the filtrate is ascertained by evaporation with a few drops of phospho-sulphuric acid adding the remainder of the acid when evaporation is almost complete and following the method of Kjeldahl as for the nitrogen test. By means of the percentage of nitrogen found, the gliadin is ascertained by multiplying by 6·25 and brought into relation with the total nitrogen substance.

Determination of glutenin.—When the percentage of gliadin is known the content in glutenin may be calculated by difference. Certain investigators prefer to determine the gluten directly and, among the methods employed mention should be made of that of Blish and Sandstedt (11).

The Blish and Sandstedt method.—Requires the following reagents :—

(1) Solution *N* of NaOH.

(2) Solution *N*/5 of HCl.

(3) Solution of Bromothymol blue (0·10 of di-bromothymol-sulphonaphthaleina are ground with 3·2 c.c. of solution *N*/5 of NaOH and brought to 25 c.c. with ethyl alcohol at 95°. It is necessary to filter).

(4) Methyl alcohol (should contain 96-99 per cent of CH_3OH and should be free from acetone).

Eight grm. of flour are mixed in a Kohlrausch flask capacity 200 c.c., with 50 c.c. of water and then shaken vigorously, and 5 c.c. of solution *N*/20 of NaOH is introduced. The mixture is shaken every 10 minutes for one hour after which methyl alcohol is added in parts of 50 c.c. at a time, shaking sharply after each addition until the 200 c.c. mark is reached. Another 5 c.c. of methyl alcohol are added to compensate for the volume occupied by the flour ; the whole is well mixed and, after the starch has fallen to the bottom, the supernatant liquid is filtered through cotton. Then 50 c.c. of this liquid is taken and introduced into an Erlenmeyer flask ; a few drops of Bromothymol blue are added and the glutenin is precipitated gradually adding by means of a burette the solution *N*/5 of HCl until a light olive colour is obtained, corresponding to a *p*H of about 6·4.

After being left to stand for one hour the contents are poured into a 100 c.c. tube and centrifuged for 10 minutes. The liquid is poured off and the glutenin is removed from the tube with a little water and placed in a Kjeldahl flask. The nitrogen is then determined and the value found, multiplied by 6·25, gives the percentage of glutenin.

In the Italian flours examined by us (using the alcohol at 70° method) no relation was found, between the relation gliadin : glutenin and the baking strength. This fact confirms results obtained by other investigators, and shows the impracticability of using such systems of research for estimating the value of the flour.

* * * * *

Determination of reducing sugars.—The quantity of sugar present in the flour after milling is almost negligible. After a few weeks of rest the formation of small quantities of sugar will be noticed which are necessary for good baking.

The dosage of sugar in flour is carried out by us according to the Bertrand method (12). It requires the following reagents :—

Solution A : 40 grm. of copper sulphate crystals are dissolved in water and brought to 1000 c.c.

Solution B : 200 grm. of Seignette salt +150 grm. of sodium hydroxide are dissolved in water and brought to 1000 c.c.

Solution C : 50 grm. of iron sulphate (free from ferrous sulphate, so that the permanganate of potash is not reduced) are dissolved in 200 c.c. of concentrated sulphuric acid and brought to 1000 c.c.

Solution D : Solution exactly $N/10$ of permanganate of potash, so that 1 c.c. of solution corresponds to 6·36 mgm. of copper.

The method of operating is very simple ; 20 c.c. of sugar solution obtained after clarifying the flour (see page 545) are treated with 20 c.c. of reducing solution (10 c.c. of solution A+10 c.c. of solution B) and boiled for 3 minutes, after which the glass is removed from the flame and the cuprous oxide precipitated (the solution left over after precipitation should remain blue) and filtered through a Gooch crucible or porous glass. After having filtered the blue liquid, the precipitate is placed on the filter and washed with water, until no traces of copper sulphate remain. The precipitate is then treated with 20 c.c. of solution C (iron sulphate) and dissolved forming a greenish solution. The glass and the crucible are washed with distilled water and the whole is collected in a flask and titrated with the solution of permanganate of potash.

The reactions take place as follows :—

(1) $Cu_2O + Fe_2(SO_4)_3 + H_2SO_4 = 2\ CuSO_4 + H_2O + 2FeSO_4$

(2) $10FeSO_4 + 2KMnO_4 + 8H_2SO_4 = 5Fe_2(SO_4)_3 + K_2SO_4 + MnSO_4 + 8H_2O.$

The proportions of glucose and of maltose corresponding to the amounts of copper obtained are shown in the annexed tables and calculated for 100 grm. of flour.

Acidity dosage.—The acidity of newly milled flour is very small and varies between pH=5·8 and pH=6·2. After a certain period of time following milling,

Table for calculating the glucose content

Glucose mgm.	Copper mgm.	Glucose mgm.	Copper mgm.	Glucose mgm.	Copper mgm.	Glucose mgm.	Copper mgm.	Glucose mgm.	Copper mgm.
10	20·4	29	57·2	48	91·8	67	124·7	86	155·6
11	22·4	30	59·1	49	93·6	68	126·4	87	157·2
12	24·3	31	60·9	50	95·4	69	128·1	88	158·8
13	26·3	32	62·8	51	97·1	70	129·8	89	160·4
14	28·3	33	64·6	52	98·9	71	131·4	90	162·0
15	30·2	34	66·5	53	100·6	72	133·1	91	163·6
16	32·2	35	68·3	54	102·3	73	134·7	92	165·2
17	34·2	36	70·1	55	104·1	74	136·3	93	166·7
18	36·2	37	72·0	56	105·8	75	137·9	94	168·3
19	38·1	38	73·8	57	107·6	76	139·6	95	169·8
20	40·1	39	75·7	58	109·3	77	141·2	96	171·4
21	42·0	40	77·5	59	111·1	78	142·8	97	173·1
22	43·9	41	79·3	60	112·8	79	144·5	98	174·6
23	45·8	42	81·1	61	114·5	80	146·1	99	176·2
24	47·7	43	82·9	62	116·2	81	147·7	100	177·8
25	49·6	44	84·7	63	117·9	82	149·3		
26	51·5	45	86·4	64	119·6	83	150·9		
27	53·4	46	88·2	65	121·3	84	152·5		
28	55·3	47	90·0	66	123·0	85	154·0		

Table for calculating the maltose content.

Maltose mgm.	Copper mgm.	Maltose mgm.	Copper mgm.	Maltose mgm.	Copper mgm.	Maltose mgm.	Copper mgm.	Maltose mgm.	Copper mgm.
10	11·2	29	32·2	48	52·8	67	73·3	86	93·7
11	12·3	30	33·3	49	53·9	68	74·3	87	94·8
12	13·4	31	34·4	50	55·0	69	75·4	88	95·8
13	14·5	32	35·5	51	56·1	70	76·5	89	96·9
14	15·6	33	36·5	52	57·1	71	77·6	90	98·0
15	16·7	34	37·6	53	58·2	72	78·6	91	99·0
16	17·8	35	38·7	54	59·3	73	79·7	92	100·1
17	18·9	36	39·8	55	60·3	74	80·8	93	101·1
18	20·0	37	40·9	56	61·4	75	81·8	94	102·2
19	21·1	38	41·9	57	62·5	76	82·9	95	103·2
20	22·2	39	43·0	58	63·5	77	84·0	96	104·2
21	23·3	40	44·1	59	64·6	78	85·1	97	105·3
22	24·4	41	45·2	60	65·7	79	86·1	98	106·3
23	25·5	42	46·3	31	66·8	80	87·2	99	107·4
24	26·6	43	47·4	62	67·9	81	88·3	100	108·4
25	27·7	44	48·5	63	68·9	82	89·4		
26	28·9	45	49·5	64	70·0	83	90·4		
27	30·0	46	50·6	65	71·1	84	91·5		
28	31·1	47	51·7	66	72·2	85	92·6		

acidity increases, particularly if the flour has a high degree of humidity and is kept in damp and insanitary surroundings. The determination of acidity in units of *p*H should be carried out by means of a potentiometric apparatus.

In the laboratories for chemical tests of flours, the acidity is determined by the ordinary methods of titration ; some adopt watery extracts of flour, others use

for extraction alcohol at various concentrations. In our laboratory the following process is used : 10 grm. of flour are placed in a graduated closely stoppered tube containing 100 c.c. of alcohol at 50° (the alcohol should be carefully neutralised before use) ; the whole is shaken for one hour, filtered and, with 50 c.c. of the filtrate, the acidity is determined with a solution of sodium hydrate or potassium hydrate *N*/20. The c.c. of ordinary alkaline solution necessary for neutralising 100 grm. of flour in the dry state express the degree of acidity.

(C) Bio-chemical methods

These methods chiefly refer to the determination of the diastasic strength of flours and the fermentation strength of the yeast.

Determination of the diastasic strength.—This determination refers to the activity of the amylase, an enzyme which works in the starch and gradually transforms it into sugar.

The presence of sugar is necessary for the life of the saccharomycetes, thus providing the possibility of obtaining a sufficient amount of carbon dioxide which is the basis for obtaining a proper leavening. The production of sugar while the flour is in store is not of great importance, but is sufficient for the needs of the saccharomycetes. The amylase slowly attacks the crude starch ; the activity of the enzymes becomes more marked during kneading and fermentation, when the saccharification of the starch is considerable.

For determining the amylase in cereals the Rumsey method (13) is most commonly used ; we have preferred to use the official process of the Moscow Research Institute for wheats and flours (1931), which varies slightly from the former method (14).

In a flask, capacity 100 c.c., 10 grm. of flour are placed and left in a thermostat at 27° for 15 minutes, then 50 c.c. of distilled water is added at a temperature of 27°. The mixture is left to stand for one hour, always at 27°, and is shaken every 15 minutes. Then 15 c.c. of solution of copper sulphate (60 grm. of $CuSO_4$) in 1000 c.c. is added ; 15 c.c. of solution of caustic sodium (12·5 grm. of NaOH) in 1000 c.c. (15) and the whole is held at a temperature of 45° to 50° for 30 minutes. It is then left to cool and brought to volume, filtered through a dry filter and the amount of sugar in the filtrate is calculated according to the Bertrand method. The diastasic strength is expressed in milligrammes of maltose per 10 grm. of flour.

For determining the true diastasic strength, it is necessary to have knowledge of the sugars already present in the flour. This may be ascertained directly, proceeding as above, but taking care that nothing remains in suspension when the mixture is placed in the thermostat. When very accurate results are required, the Moscow Institute proceeds as follows : 10 grm. of flour with 20 c.c. of alcohol at 78° contained in a flask, capacity 1000 c.c., are first heated in a bainmarie for

10 minutes, the alcohol is evaporated completely, 20 c.c. of distilled water is added and the preceding method is followed. The quantity of sugar found that corresponds with the sugar present in the flour should be subtracted from the first result.

Is the amylase of great importance as regards baking ? Is there a relation between the quantity of amylase and the baking value ? Certainly the amylase plays an important part in baking, though this should not be exaggerated. In practice, it is found that hard wheat flours—excellent for making pastes, but unsuitable for baking have a high diastasic strength superior to that of ordinary baking flours. In practice, the diastasic strength of Italian wheats and flours has proved to be generally sufficient for baking purposes and in the contrary case it would be easy, with the addition of appropriate substances, to obtain as much as might be required. It should also be mentioned that, in baking, the high temperature causes appreciable quantities of hydro-alcoholic vapours to form, which, together with the gases produced by fermentation, exercise an action of considerable importance in the phenomena of bread making.

The above mentioned and similar methods cannot give very reliable results inasmuch as the determination is carried out, not with the dough, but with as suspension in which the enzymetic action is not comparable as the conditions are totally different.

It should be added that many writers still attribute great importance to the quantity of gas developed and determine the activity of the amylase indirectly, measuring the quantity of gas which develops in the dough when yeast is added. Such testing is very simple : the gas obtained in the dough, containing a given quantity of yeast (generally 1 to 2 per cent), is collected by means of ordinary volumenometers ; or is determined by means of simple gas registering apparatus at constant pressure (16).

Brabender has constructed an apparatus, called a Fermentograph, based on the principle of the hydrostatic balance, with which is determined graphically the carbon dioxide developed by a given quantity of flour kneaded with yeast and salt [Mehlprobleme, 1932, Duisberg].

Undoubtedly a deficiency of gas—which ordinarily never occurs—has an adverse effect on successful baking ; it is much more important to know the quantity of carbon dioxide that remains in the dough than the quantity developed. Bailey and Weigley, who in their experiments have used ordinary graduated tubes for measuring the volume of the dough, have determined that the dough of strong flours lose less carbon dioxide than weak flours and, on the other hand, the more carbon dioxide is retained the greater the volume in dough. L. Borasio has arrived at the same conclusions in his recent tests (17). In fact, the good quality of a flour depends on its capacity to retain the gases of fermentation.

Determination of the fermentation strength of yeast.—Up to the present experiments have been limited to determining the fermentation strength by means of the Hayduck method. In this method 40 g. of sucrose are dissolved in water and the whole is brought to 400 c.c.; 50 c.c. of this solution is taken and, using a small mortar, 10 grm. of compressed yeast are added. The whole is put in a receptacle of 500 c.c. closed with a cork and attached, by a rubber tube, to a volumenometer full of water saturated with sodium chloride so as to prevent the absorption of the carbon dioxide developed.

The determination is made in a bainmarie kept at 30° and yeast is considered good which develops 250 c.c. of gas in 90 minutes.

Other writers suggest the use of a sugar solution for determining the gas developed in the dough obtained by adding water and given quantities of yeast, although the Hayduck method is more generally used.

(*D*) *Physico-chemical methods*

The most important physico-chemical determinations relate to: (1) the capacity for absorbing water; (2) the degree of hydration of the gluten; (3) the degree of extensibility of the gluten.

The capacity of flour to absorb water depends on its hydrophilous constituents and is generally determined by the baker. It is advisable always to employ the same operator so as to obtain congruent data.

In order to render this determination more scientifically accurate and less subjective, Swanson and Working (18) introduced a method by which the water, left in a flour after centrifuging, is measured. The results obtained do not always correspond with reality; to obtain more accurate methods, it is necessary to employ apparatus designed for this purpose, among which should be named the electro-mechanical "Farinograph" of Hankoczy-Brabender and our "Elettroviscosigrafo", which registers graphically the consistency of a dough and, therefore, determines the degree of absorption of the flour.

In addition to these types of apparatus which function well and will be described later on, the degree of water absorption may be determined by purely mechanical means (19). The apparatus invented by us, called the "Consisten ziatore", consists of a motor which drives a kneading machine, constructed for this purpose, by means of a couple of cogwheels with a worm screw. This screw, which turns on the axle of the motor in spiral grooves, is held in place by a tared spiral spring which functions as a shock absorber. To this is attached a lever which controls an index needle, varying according to the power developed by the kneading machine, and gives the exact consistency obtained. One hundred and fifty grm. are used which are kneaded, first rapidly, adding a given quantity of water (about 70 c.c.) and then more slowly, until the standard consistency is obtained. The c.c. used calculated for 100 grm. of flour give the degree of water absorption.

Degree of hydration of the gluten.—Arpin (20) has introduced a process for determining this constant. The extracted gluten is dried by means of an apparatus invented by himself and called " L'Essoreuse ". This consists of two cylinders of vulcanite which turn in opposite directions at a distance of 0·4 mm. apart. The gluten, after having been passed through 8 times, is weighed moist and then dried at 105° and the difference in weight gives the degree of hydration which is calculated as a percentage.

Determination of the extensibility of the gluten.—Berliner and Koopmann (21) have suggested a method, based on extensibility, for estimating the quality of a flour, which will now be briefly described : 2·5 grm. of gluten, extracted with a solution of NaCl at 2 per cent are divided into 70 small pieces and left for two hours and a half in a special patented flask, with 250 c.c. of lactic acid *N*/50 at a temperature of 27°. After this period the volume is read off directly from the neck of the flask. This volume in c.c. is divided by 2·5 and the result obtained is called the extensibility index and varies between 4 and 29.

Berliner has recently modified his process, working only with 1 grm. of moist gluten and 100 c.c. of solution (D. R. P. 525594).

Apart from the difficulty of this process (due to the fact that it is almost impossible to divide the gluten into so many small pieces of equal weight), the method may give data that are fairly in agreement (particularly within the extreme limits), but it has the disadvantage of limiting the investigation to the extensibility of the gluten, an important but not the only factor for estimating the baking strength of flour, since, if substitutes are added, it is impossible to indicate with such data the quality of a mixed flour.

The data which most closely approach true facts, are those obtained by mechanical methods.

(*E*) *Mechanical methods*

Mechanical methods may be divided into two categories : (1) methods based on examination of the gluten—(2) methods based on examination of the dough.

Among the instruments used for investigations of the quality of the gluten, mention should be made of the Bolland apparatus (22), known as the " Aleurometer " now in use, and the " Gluten Tester " of Liebermann [1900] ; both very inexact instruments based on the measurement of the expansion of the gluten by means of heat.

Hankoczy Farinometer (1910)

The Hungarian scientist, Hankoczy (23) was the first, to invent, in 1905, an apparatus for measuring the elasticity of gluten by means of the action of air pressure, provided by a column of mercury, on a thin layer of that substance. This apparatus was afterwards improved and introduced in 1910 for determining the physical properties of dough.

At the present time it is preferred to operate on the dough rather than on the gluten as, in addition to the difficulties of extraction, gluten extract has not the same characteristics as the gluten still contained in the dough, while the physical characteristics of dough, though for the most part dependent on the gluten, are also dependent on the presence of other component elements (starch, sugars, dextrin, protein, cellulose, etc.), all of which contributed towards the suitability or otherwise of flour for baking purposes.

Numerous kinds of apparatus have been invented, the two most important being the Chopin " Extensimeter " and the Borasio-De Rege " Pneumodynamometer ".

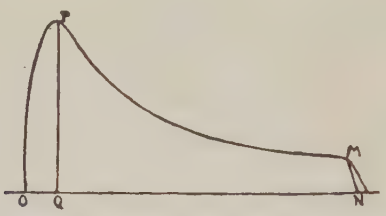

Fig. 1. Graph obtained with the " Extensimeter ".

The composition of the dough, the process of separation, the duration of kneading and of the rest period and the other manipulations should always be carried out according to the same system.

The Chopin Extensimeter is extensively employed and curves are obtained with it which have the following characteristics :—

P = tenacity, calculated by the maximum pressure registered : PQ ;

G = square root of the volume of the bubble at the moment of breaking ;

W = average working effect divided by the weight of the layer of dough.

Chopin writes that, for a flour to satisfy purchasers from the point of view of its plastic quality, the raising effect W should be as near as possible to a determined value corresponding to a given region (quality of the wheat used in that region and the system of baking employed). Thus for Paris this value is fixed as W = 100.

Chopin is of opinion that such value should not fall below a determined limit, *e.g.*, below 20 for Paris.

The apparatus works under pressure and the results are fairly good, though the speed of the escape of air is rapid and irregular, for which reason the curve has characteristics that are not absolutely exact. The determination, that is made on the basis of the volume of water reached as read off by the operator on the graduated column of the apparatus, is also subject to error on account of the rapidity of the test.

The " Pneumodynamometer " invented by Borasio and De Rege (24) is completely automatic and very accurate.

The outstanding merits differentiating the " Pneumodynamometer " from other similar apparatus, increase its practical and scientific value and depend on the fact that, in addition to the advantages and facility of a specially devised automatic device, the quantity of air is kept strictly constant and is not influenced by the different resistances of doughs made of various flours.

The curve expresses the force exercised by the air in modifying the form of the layer of dough and the area, enclosed in the curve, is called the strength of the flour.

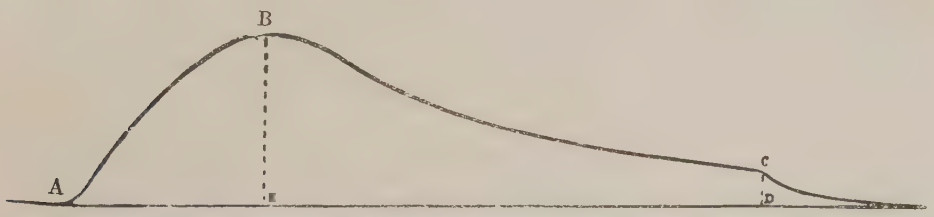

Fig. 2. Typical graphs obtained by the " Pneumodynamometer ".

From the graph traced by the " Pneumodynamometer " important indication may be obtained, allowing the quality of a flour to be estimated most completely (25). These indications are the following —

(1) Tenacity, represented by the maximum ordinate of the curve which is given by the segment B E, indicating the pressure in mm. of mercury.

(2) Elasticity, volume in c.c. of the bubble at point B.

(3) Extensibility, volume in c.c. of the bubble at the moment of breaking.

(4) Ordinate of breaking, represented by the segment D measured in mm. of mercury.

(5) Relation extensibility : Elasticity.

(6) Strength of the flour, area ABCD in c.c., enclosed by the curve.

(7) Working effect=extensibility $\times$ flour strength.

The most important data are extensibility and strength ; it should, however, be noted that flours frequently occur with slight resistance capacity and great extensibility, or on the other hand, with great resistance capacity, but deficient in extensibility.

The working effect, equivalent to the product of strength multiplied by extensibility, is in proportion to the modifying effect produced by gases acting on

the dough, and includes these characteristics, so that if one or the other is absent or even is not very marked, the effect will be *nil* or slight, and in this way the quality of a flour may be judged.

Taking the values of the index of working effect as a basis, the writers have fixed limiting values for this index, thus giving the following classification of flours :—

Inferior	500—1,500
Mediocre	1,500—3,000
Good	3,000—4,500
Superior	above 4,500

The Chopin apparatus and the Pneumodynamometer register the strength employed in dilatation and allow the modifying activity in the dough to be ascertained. This work activity is the most interesting and important from the point of view of baking as it is that which operates in the phenomena of fermentation and baking.

It certainly cannot be stated that there is any absolute agreement between the curves and the baking tests on account of the many complex phenomena, chemical, bio-chemical and physico-chemical, which arise during the process of baking ; at the same time it should be recognised that these instruments provide the most accurate method of estimating the quality of a flour. Their precision gives them a special value, both from the practical and scientific points of view, and makes it possible to study many problems regarding the properties of dough. Among these, one of the most important is that concerning the strengthening of flour, *i.e.*, a knowledge of the quantity of strong flour required in order to strengthen a weak flour. This problem may be solved by a simple calculation and, if, for obvious reasons due to the influence that certain components in the flour exercise in the mixture, accurate results are not obtained, they are at least approximately correct and provide a satisfactory criterion for estimating the percentage required (see L. Borasio, Studi sulle farine di grano, Vercelli, 1934).

(*F*) *Methods based on the measurement of the force required for kneading*

If the work of a kneader is observed, it will be seen that the energy output required in kneading differs according to the quality of the flour. On this principle are based the Farinograph of Hankoczy and Brabender, the Electroviscosigraph in our laboratory, the dynamometric kneader of Feyte and Potel and the apparatus devised by Swanson and Working.

In 1912, Hankoczy invented the Farinograph, which was improved between 1927 and 1930 and brought to its present form in collaboration with Brabender. This apparatus, which works with an electrodynamometer, registers under the form of a curve the physical characteristics of the dough and also determines the capacity for water absorption in the flour. This factor is determined in a preliminary test by adding to the flour the quantity of water necessary for obtaining a dough of a previously established consistency. According to Brabender

this determination is carried to a high degree of precision (0·2 per cent) ; a degree of sensitiveness so high actually does not exist.

Investigations on the baking quality of the flour are carried out on 300 grm. of flour at constant consistency, working, according to Hankoczy, for 15 minutes. Many factors may be obtained from the graph, though Hankoczy considers two only, namely :—

(1) the duration of rising in the dough, calculated in minutes from the beginning of the curve to the moment at which the curve no longer ascends ;

(2) weakening or fall in consistency expressed in cm^2, which is determined by measuring with a planimetre the area comprised between the ordinates corresponding on the one hand to complete rising and on the other to the ordinate of the 15th minute of kneading.

By the use of these methods, Hankoczy suggests a classification based on the duration of kneading and the fall in consistency (26).

Does, however, Hankoczy's classification correspond with the baking test and is there a relation between the curve obtained and the experimental tests ?

It cannot be denied that a relation does exist between the course of the curve and the baking value ; a relation which is sometimes uncertain in respect of certain flours and particularly in mixtures containing substances with a high power of absorption.

Hankoczy attributes this to the fact that the dough, while having a satisfactory consistency, has not sufficient elasticity and extensibility to retain the gases of fermentation and the bread obtained is, therefore, relatively small in volume.

Similar results are obtained with the dynamometer of Feyte and Potel, with the " Elettroviscosigrafo ", and with the apparatus of Swanson and Working (27). The following facts have been determined by means of the first instrument :—

(*a*) that the effort required in kneading a flour is proportional to the duration of the process ;

(*b*) that operating under the same conditions as for testing with the Extensimeter of Chopin, a proportional relation has been observed between W (work) and the force required for kneading.

Using the " Elettroviscosigrafo ", which the writer has devised for measuring the output of effort in kneading by means of a registering wattmeter, it has been possible to determine :—

(1) that the absorption of force varies according to the flours ;

(2) that there is no relation between this force and the baking value, as the relation between the baking value, and the curves traced at equal consistencies is not invariable ;

(3) that the absorption capacity is not a function of the baking quality ;

(4) that as colloidal substances are involved, many factors have a considerable influence on the behaviour of the curves, such as the type of kneader employed, its speed, the temperature, the chemical substances added, etc.

All these instruments are based on the principle of the degree of working under pressure. In our opinion, this working is not quite comparable to that which the dough undergoes during fermentation and baking. In fact, it is true that in mixtures containing substances with a high capacity for absorption (rice, facula, carob, clay, gesso, etc.), the working under pressure and the consistency of the paste increase considerably and register excellent curves from every point of view, but the practical results are not satisfactory, as they do not correspond to the baking tests.

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(1) In order to facilitate the colour test special apparatus with photo-electric cells have recently been introduced which determine the light reflected by the flour.

(2) KENT JONES, *Modern Cereal Chemistry*, 1927, Liverpool.

(3) KURSCHNER and HANACK, in *Zeitschrift für Untersuchung der Levensmittel*, Berlin 1930, **59**.

(4) BELLUCCI, in *Annali di Chimica applicata*, Roma 1932, **22**.

(5) MAROTTA and VERCILLO, *Ibidem*, 1932, **22**.

(6) BERLINER and KOOPMANN, in *Mitteilungen uber Lebensmitteluntersuchung*, 1929, **20**.

(7) DILL and ALBERG, in *Zeitschrift für Untersuchung der Lebensmittel*, Berlin 1930, **59**.

(8) The standard solution is obtained thus : a certain quantity of magnesium free sodium chloride at 2 per cent is prepared and used as a solvent, two concentrated solutions are prepared (for example, 4 per cent of anhydrous salt) ; one of bi-sodium phosphate and the other of mono-sodium phosphate and are mixed in such proportions as to obtain pH = 6·8 (Bromothymol blue indicator). This solution is diluted with the solution of sodium chloride previously prepared so as to obtain a concentration 0·1 per cent of anhydrous salt. When used the solution should be kept at 18°.

(9) SNYDER, in *Journal of the Chemical Society*, 1905, p. 1068.

(10) FLEURENT, in *Comptes rendus de L'Academie des Sciences*, Paris 1896, tome **123**, p. 755.

(11) BLISH and SANDSTEDT, in Cereal Chemistry 1925, **2** ; 1927, **4**.—*Journal of the Association of Official Agricultural Chemists*, Menasha (Wisconsin) 1926, **9**, p. 417.

(12) BERTRAND, in *Journal de las Societe de Chimie biologique*, Paris 1906, **35**, p. 1285.

(13) RUMSEY, in *American Institute of Baking Bulletin*, 1922.

(14) The difference between the Russian method and that of Rumsey is that: in the latter the clarification is carried out with the aid of 3 c.c. of solution of sodium tungstate at 15 per cent and 5 drops of solution of Thymol blue at 0·04 per cent, sulphuric acid being then added drop by drop until a rose colour is obtained. The acidity of the solution may be caused by the inversion of small quantities of the sucrose present in the flour, which brings about an increase in the maltose content. For this reason the Russian method, which works under alkaline conditions, gives more precise data.

(15) Clarification may also be carried out using 15 to 20 c.c. of solution of zinc sulphate at 4·5 per cent, solution of sodium hydroxide at 4 per cent, the whole being heated at 45° to 50° for 30 minutes.

(16) MARKELY and BAILEY, An automatic method for measuring gas production and expansion in doughs.—*Cereal Chemistry*, 1932, **9**.

ROY IRVIN, An improved apparatus for measuring gas production and expansion in doughs.—*Ibidem*, 1935, **2**.

(17) In order to obtain data which correspond more closely with reality, BORASIO carried out fermentation tests operating on small loaves of 100 grm. of flour which were left to ferment freely without any external influence so as to ascertain their true capacity for expansion and growth. The flour was kneaded with 2 per cent of ordinary compressed yeast of regular consistency; the volume of the loaf before fermentation is carried out in a graduated tube with the addition of water; the quantity of gas developed is determined with ordinary volumenometers; the volume reached by the loaf is measured approximately with volumenometers which function with the displacement of liquid. The baking ovens are kept at 30°. (See L. BORASIO *Studi sulle farine di grano*, Vercelli, 1934).

(18) SWANSON and WORKING, in *Cereal Chemistry*, 1933, **10**.

(19) See for the apparatus invented by these writers, *Ibidem*, 1933, **10**.

(20) ARPIN, *Farines, fecules et amidons*, Paris, 1913.

(21) BERLINER and KOOPMANN, in *Zeitschrift für das gesamte Muhlewesen*, 1929.

(22) BOLAND, in *Revue des Services de l'Intendance*, Paris, 1888.

(23) HANKOCZY, in *Molnarok* Lapja, Budapest, 1905.

(24) BORASIO, L. and DE REGE, F., in *Giornale di Risicoltura*, Vercelli, 1932 et 1933.

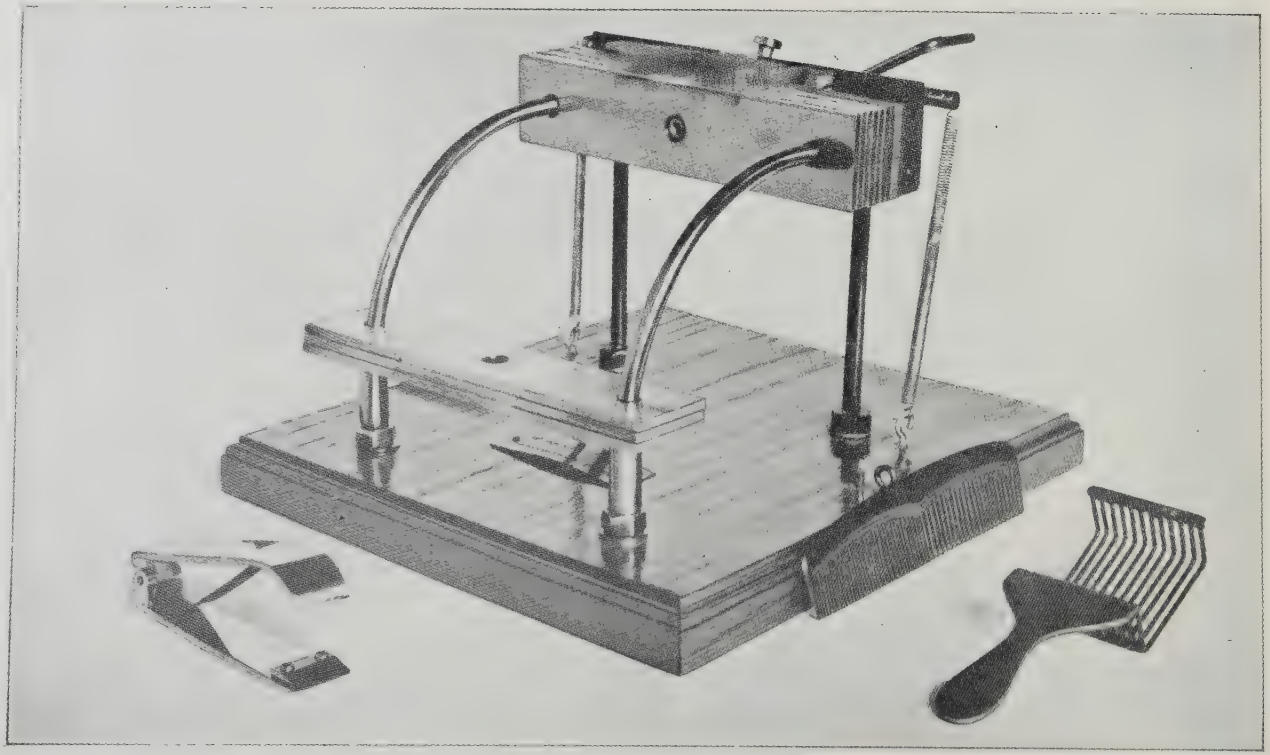
(25) Id., Id., *Istruzioni per l'impiego dell' apparecchio*, Vercelli, 1934.

(26) Scale showing the numerical values of the curves, as adoped by Hankoczy—

Length of kneading process	Points	Fall in consistency	Points
10 minutes	100	0 cm²	100
1 minute	1	60 cm²	0

The two points, found for every flour, are added together, divided by 2 and the result gives the numerical value. Hankoczy, for studying exhaustively the properties of a flour, determined with the Farinograph the consistency of a dough containing salt and yeast in given percentages and kneading took place alternating with periods of fermentation. The curve obtained was compared with that of the development of the CO_2 obtained with the Fermentograph. According to the writer the data obtained with the Farinograph are thus integrated and more accurate results are obtained. (See *Mehlprobleme*, 1932, Duisburg).

(27) The Swanson-Working apparatus is merely a small standard kneader to which is attached a registering wattmeter or a dynamometer apparatus. The investigations on the determination of the degree of water absorption have given satisfactory results particularly with the completely mechanical apparatus.



Seed-cotton-fiber sorter, showing mechanical features of construction with three combs in resting position, together with comb, forceps, and pusher.

[Reproduced from the *United States Department of Agriculture Circular No.* 360.]

ABSTRACT

A device for separating different lengths of fibres from seed cotton. HOMER C. MCNAMARA and ROBERT T. STUTTS (*United States Department of Agriculture Circular No.* **360**, *August 1935*).

[With Plates LXIV & LXV]

SUMMARY

A simple device for determining the variation in fibre-length on a single seed of cotton would greatly help the cotton breeder as it would enable him to evolve strains which possess greater uniformity in length.

The device (Plates LXIV & LXV) described in this circular consists of a set of brass combs each $\frac{1}{16}$ in. or $\frac{1}{8}$ in. thick mounted side by side on two guide rods, which curve down to the base plate. The combs are held in position by a screw by turning which each comb is successively released and glides down the guide rods on the base. A metallic bar with an adjustable spring tension serves to hold the combed seed in a cavity provided for it behind the combs. The authors recommend combs having 24 teeth to an inch, each tooth being $\frac{1}{64}$ in. in diameter as being the most suitable. The accessories required are a spare comb, forceps and a wire depressor for slipping the fibres into the combs.

In performing a test, the seed is combed into a " butterfly " taking good care to remove or break as few fibres as possible in the combing process. The combed seed is placed in the cavity provided for it in such a manner that the fibres on one side lie at right angles to the combs. These fibres are pressed down with the wire depressor and the seed is held in position by the tension bar. A few combs are released until the ends of the longest fibres just project beyond the combs. These are gripped with a tweezer, pulled out and laid on a velvet plush. Another comb is released and the operation is continued until all the fibres on one side of the seed are extracted and laid on the plush. This will enable the worker either to form the complete array or to estimate the percentage of fibres above a certain length.

Details of some experiments conducted for the purpose of determining the most suitable size and spacing of the teeth of the comb are given with photographs.

The authors found that the amount of hairs removed during the preliminary combing process depended upon the tester and showed a tendency to increase with the longer staple. Further, the combed hairs contain fibres of all lengths borne on the seed, but among these there is an excess of shorter fibres.

The chief sources of error discussed are (1) while the fibres are assumed to be aligned at the basal end, they are actually distributed over the curved surface of the seed ; consequently the base of each group length extracted will be uneven, (2) there will be a slight curling of the fibre ends when gripped by the forceps.

A transparent sheet of celluloid with a series of horizontal lines one-sixteenth of an inch apart from a common base line serves to measure the individual group length.

Abstractor's Remarks

Uniformity in fibre-length is a valuable asset and any simple device which would help the cotton breeder to choose a more uniform variety should be welcome.

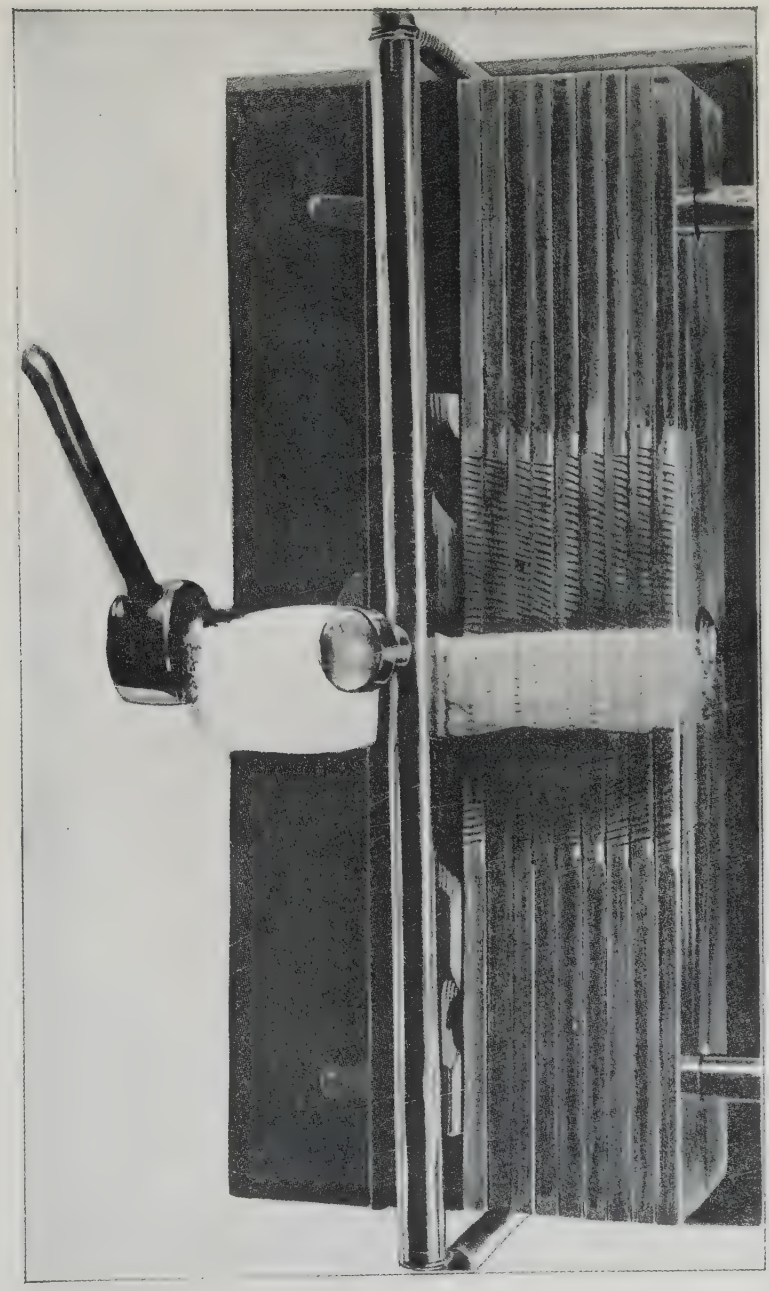
In the present case, in addition to the source of error discussed by the authors, there is one which has apparently been overlooked by them. If the cotton fibre is nipped at the ends and stretched, in most cases it will break at or near the apical end where the fibre tapers and is consequently weak. In an investigation* carried out at this Laboratory it was found that nearly 80 per cent of the fibres broke near the apical end. In view of this the usual practice in removing fibres from the seed is to grip them as near the seed-surface as possible. In the method under review, after the seed is placed behind the combs the fibres are nipped in the tweezer at their apical end and pulled. It is highly probable that in this process some of the fibres will break and consequently the array obtained will not be truly representative. It would have been highly useful if the authors had given comparative results for the same cottons as arrayed by the present method and by an older method.

In this connection it should be noted that the number of hairs which might break on pulling near the apical ends will vary with the variety, as it will depend upon the tenacity with which the fibres are held by the seed. Hence, this error will be variable, and not constant, for the different varieties.

The authors state that in the combing waste there was an excess of shorter fibres, resulting in lowering the mean fibre-length of this waste. In the experiments performed at this Laboratory to which a reference has been made above, no such effect was observed. This lack of agreement may either be due to the peculiarity of the cottons concerned, or to the difference in the amount of force applied in disentangling the fibres. The latter explanation is more likely as the authors removed from 12·8 to 22·3 per cent fibres in the combing process as against 7 per cent to 17 per cent in the experiments performed at this Laboratory.

Finally, it should be mentioned that owing to the variation from seed to seed, it would be necessary to test a moderately large number of seeds to avoid large sampling error. (Nazir Ahmad).

* Variation in the Properties of Cotton Fibre in relation to its Position on the Surface of the Seed, by R. S. Koshal and Nazir Ahmad, *Ind. Cent. Cot. Com., Tech. Bull., Series B*, No. 14.



Close-up view of seed-cotton-fiber sorter.
[Reproduced from *United States Department of Agriculture Circular No.* 360.]

REVIEW

Plant Breeding Abstracts Supplement II: Summary of Reports received from stations in the British Empire, 1932-35. [Compiled by the Imperial Bureau of Plant Genetics (for Crops other than Herbage), School of Agriculture, Cambridge.] 63 pp. Price 5*s*.

This Supplement to Plant Breeding Abstracts which has been compiled from the annual reports received at the Imperial Bureau of Plant Genetics, Cambridge, is intended to give a concise account of the work on plant breeding and related topics in the British Empire during 1932-35 and one which will be at the same time in a convenient form for reference. The amount and range of plant breeding work in the British Empire is of course enormous and the publication has involved the scrutiny of over 400 reports.

Much of the work referred to is only available in annual reports, being more or less of a routine nature, and but for the activity of the Imperial Bureau of Plant Genetics would have remained inaccessible to the general reader. Another valuable feature of the Supplement is that many of the items included concern work which though likely to be published in the future has not yet reached that stage.

The crops dealt with cover practically the whole range of economic plants with the exception of herbage plants and the work reported includes breeding, genetics and cytology. There is also a section on the genetics of plant parasites.

The Supplement is very comprehensive and is planned in such a way that the work on a given crop in a given country can be turned up at once; an extensive index is also provided.

Reviews of this kind are invaluable to practical breeders in giving a survey of the work in progress in the whole field of plant breeding and should be read with interest also by all those interested in modern genetics and its application to agricultural plants.

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ERRATA

The Indian Journal of Agricultural Science, Vol. VI, Part II, April 1936.

Page 189, line 10 from bottom, *for* 'Local' *read* 'Locust'.

Page 190, heading 2, *for* *'Schistocerca Gregaria'* *read* *'Schistocerca gregaria'*.

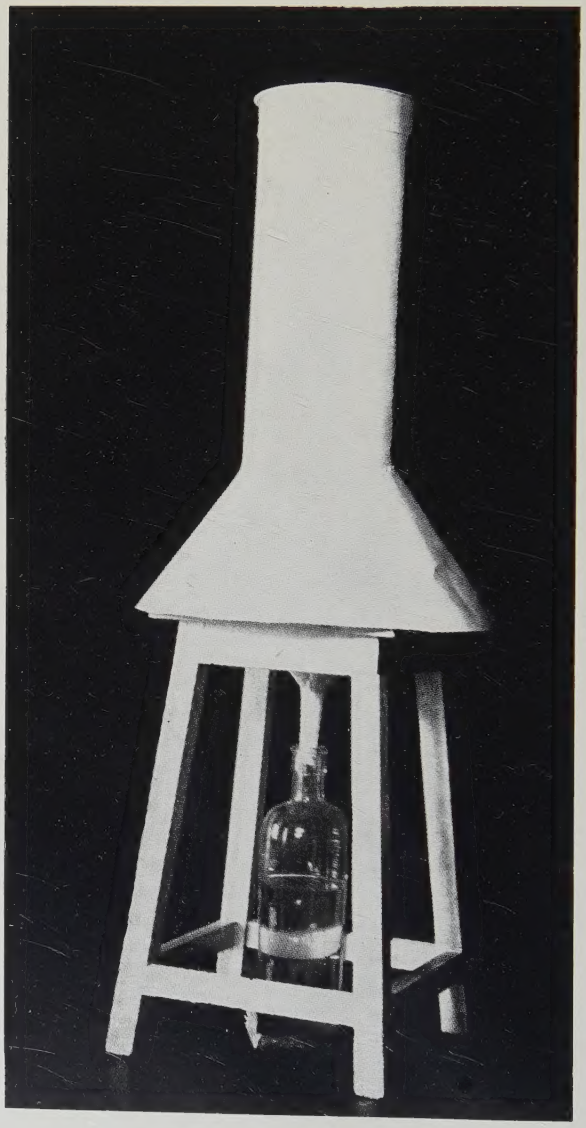
Page 195, heading of Table IV, *for* *'28-32 C'* *read* *'28-32° C'*.

Page 196, line 3, *for* *'rythm'* *read* 'rhythm'.

Page 207, line 4, *for* 'sandy-loan' *read* 'sandy-loam'.

Page 218, line 3 from bottom, *for* 'eigh thours' *read* 'eight hours'.

Page 263, footnote, line 3 from bottom, *for* 'It is implied' *read* 'It is not implied'.



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